U.S. Coast Guard Research and Development Center

1082 Shennecossett Road, Groton, CT 06340-6096

Report No. CG-D-05-03

Cape Henry Lighthouse Fuel Cell Evaluation

FINAL REPORT
March 2003

This document is available to the U.S. public through the
National Technical Information Service, Springfield, VA 22161

Prepared for:

U.S. Department of Homeland Security
United States Coast Guard
Systems (G-S)
Washington, DC 20593-0001

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **00 MAR 2003**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Cape Henry Lighthouse Fuel Cell Evaluation**	5a. CONTRACT NUMBER **N00014-02-C-0269**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Coast Guard Research and Development Center, 1082 Shennecossett Rd., Groton, CT 06340-6096**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**47**	

N O T I C E

This document is disseminated under the sponsorship of the Department of Homeland Security in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

This report does not constitute a standard, specification, or regulation.

Marc B. Mandler, Ph.D.
Technical Director
United States Coast Guard
Research & Development Center
1082 Shennecossett Road
Groton, CT 06340-6096

Technical Report Documentation Page

1. Report No. CG-D-05-03	**2. Government Accession Number**	**3. Recipient's Catalog No.**
4. Title and Subtitle Cape Henry Lighthouse Fuel Cell Evaluation		**5. Report Date** March 2003
		6. Performing Organization Code Project No. 9010
7. Author(s) Robert C. Desruisseau, Walter B. Lincoln, and Dr. Stephen J. Allen		**8. Performing Organization Report No.** R&DC 445
9. Performing Organization Name and Address U.S. Coast Guard Research and Development Center 1082 Shennecossett Road Groton, CT 06340-6096		**10. Work Unit No. (TRAIS)**
		11. Contract or Grant No. DTCG32-01-N-R00011
12. Sponsoring Organization Name and Address U.S. Department of Homeland Security United States Coast Guard Systems (G-S) Washington, DC 20593-0001		**13. Type of Report & Period Covered** Final Report
		14. Sponsoring Agency Code Commandant (G- SEC) U.S. Coast Guard Headquarters Washington, DC 20593-0001

15. Supplementary Notes

The R&D Center's technical point of contact is Mr. Robert Desruisseau, (860) 441-2660, email: rdesruisseau@rdc.uscg.mil.

16. Abstract (MAXIMUM 200 WORDS)

The U.S. Coast Guard (USCG) operates several hundred remote communications stations, radio navigation stations, weather stations and aids to navigation stations. Often these sites draw power from aging, inefficient power sources or unreliable underwater power lines, which are costly to repair and frequently out-of-service. Some of these sites are in environmentally sensitive areas, and in many instances, historical restrictions limit the use of solar panels. In the past few years, low power fuel cell systems have emerged as a potential option in the suite of remote power technologies. Fuel cells are highly efficient, environmentally benign devices that combine hydrogen and oxygen to create electric power.

In order to assess the potential of fuel cells in an operational marine environment, the USCG Research and Development Center conducted a demonstration at the Cape Henry Lighthouse in Virginia Beach, VA. The Cape Henry installation used a three-kW direct methanol fuel cell. Placed in operation in March 2002, the system ran for approximately six months. Performance data such as fuel consumption, power output, and reliability were collected and compared with conventional technology. An evaluation of costs, safety, training, fuel logistics, etc., was conducted to assess the potential for future use of fuel cells at other Coast Guard operational sites. Results of this demonstration were mixed. Several problems with fuel supply and overheating were experienced. It was concluded that fuel cell systems were not ready for unattended remote operation at Coast Guard sites. However, the technology has significant promise and should be closely monitored by the USCG as manufacturers introduce more reliable systems.

17. Key Words fuel cell, lighthouse, alternative energy	**18. Distribution Statement** This document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161

19. Security Class (This Report) UNCLASSIFIED	**20. Security Class (This Page)** UNCLASSIFIED	**21. No of Pages** 48	**22. Price**

Form DOT F 1700.7 (8/72) Reproduction of form and completed page is authorized.

ACKNOWLEDGEMENTS

Thanks to MK1 Joeseph Baird, Group Hampton Roads Engineering; CWO Barry Disbrow, ELC Baltimore, MD; Ms. Jennifer Hunt, Mr. Bill Keil, and Mr. Otto Olsen of Fuel Cell Energy; and Mr. Samuel J. Hartman, Post Operations Officer, U.S. Army Fort Story.

EXECUTIVE SUMMARY

Responding to the U.S. Coast Guard's need for clean, reliable and economic electric power at several hundred remote sites, the U.S. Coast Guard Research and Development (R&D) Center undertook an evaluation of low-power fuel cell systems. At the time that this project was initiated in early 2000, several fuel cell manufacturers had demonstrated prototype systems primarily for residential applications. These systems ran on either natural gas or methanol, and provided a power output of 3-7 kilowatts, which is typical of a residential load, and roughly the power load of many Coast Guard remote sites. The R&D Center's objective was to evaluate whether these emerging fuel cell technologies could provide a superior product within the existing Coast Guard suite of power technologies (i.e., diesel generators, solar, wind, submerged cables).

In early 2002, with partial support from the Department of Energy, the Coast Guard R&D Center contracted with Fuel Cell Energy (FCE), Inc. of Danbury, CT, to install a three-kW direct methanol fuel cell at the Cape Henry Lighthouse located at U.S. Army Fort Story in Virginia Beach, VA. This site was selected as an operational site because it closely replicated that of a remote site, i.e., the oil building that would house the fuel cell and ancillary equipment had no electricity, heat or running water. The building was close to the ocean and it was logistically supportable during the prototype demonstration for fuel deliveries and servicing. In order to maintain continuous navigational lighting, the fuel cell system powered a separate lighting system identical to that of the adjacent lighthouse. The prototype system was operated for a period of approximately six months during which technical performance data, including fuel consumption, power availability, and stack temperatures, were recorded. Operational performance data such as installation costs, fuel costs, training, and safety were also evaluated during this period.

Safety emerged as an important and time-consuming issue for this project because the fuel, a mixture of methanol and water, had not been used by the Army and was not included in their handling systems. A preliminary hazard analysis was completed at the R&D Center to identify the most likely causes of catastrophic failure. This analysis and the engineering of the fuel delivery/handling system for the fuel cell resolved the safety concerns.

Results from this fuel cell demonstration were mixed. On the negative side, the initial cost of the fuel cell was many times higher than that of a comparably-sized diesel generator. The fuel cell was also considerably larger and heavier. The cost per BTU of the methanol/water fuel mixture was higher than that of diesel fuel (partly due to the small quantities used); a greater fuel volume is required for equivalent energy. Several problems with fuel supply were initially experienced, causing the fuel cell to shut down day after day during the first few weeks of operation. In two instances, equipment overheated and caused shutdowns. Operator error caused the system to shut down twice. There was only one occurrence of an internal failure to the fuel cell and that was with the fuel injector. Once recognized, each problem could be easily fixed. The system shutdowns caused the system to be off for 14 percent of the time. These problems demonstrated that, for the chosen system, overall reliability was insufficient for actual Coast Guard operational requirements.

On the positive side, the system efficiency for the total running time of 4090 hours was calculated to be 37.2 percent. The highest efficiency calculated was 39.6 percent. For comparison, a small diesel generator in the five-kW range would have efficiencies around 20 percent, while a diesel generator in the 300-kW range might approach 39 percent. An additional aspect relating to the fuel cell efficiency is that, throughout the entire test, the building was heated by the fuel cell exhaust (temperature 120 ºC), which was vented to the outside. If this waste heat could be recovered productively, a conservative estimate would add five to ten percent to the overall efficiency, bringing it up to 43 percent. Once the system problems were identified and corrected, the system achieved reliable power output. The fuel cell component of the overall system ran flawlessly. The system was safe, and maintenance was not beyond the level of a trained technician. The fuel cell produces fewer harmful emissions than a diesel generator.

Overall, the fuel cell system offered significant potential. As manufacturers commercialize fuel cell products, the Coast Guard should continue to monitor their progress. It is anticipated that, over the next few years, fuel cell power systems will become less expensive and more reliable. When the technology is fully developed, the Coast Guard should re-evaluate adding fuel cells to its existing power options.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS/ACRONYMS

A	ampere	AC	alternating current
ATON	aids to navigation	DAS	data acquisition system
DC	direct current	DOE	Department of Energy
FCE	Fuel Cell Energy	K	1000
KW	kilowatt	PLC	programmable logic controller
R&D	research & development	UPS	uninterruptible power supply
USCG	United States Coast Guard	V	volt
W	watt		

1 Background

1.1 Remote Power Need

There is a need at all Coast Guard facilities for clean, reliable and economic electric power. This need is especially critical at the several hundred unattended remote sites, which include communications stations, weather stations, lighthouses, and lighted structures with audible sound signals. Reliable power is critical since its loss may result in marine or aviation accidents. Appendix A describes many of the Coast Guard potential applications for small fuel cells. Many of these sites now rely on submerged cables, diesel generators, batteries, solar panels, wind turbines or thermoelectric generators. These technologies have proven to be mature systems that have fulfilled the Coast Guard's power needs, yet for each technology there are advantages and disadvantages. An overview of the limitations of existing power sources for Coast Guard remote sites is contained in a "Systems Times" article (Lincoln, 1999).

Furthermore, many of these structures are located in environmentally sensitive coastal areas and must conform to stringent historic, esthetic and zoning restrictions. At this time, there is no perfect electric power source with present technology. Issues of high capital cost, high operation and maintenance costs, reliability, and environmental benevolence, are all considerations in selecting the appropriate power source for remote site applications.

1.2 Fuel Cell Technology

Fuel cells are intrinsically simple electrochemical devices that combine hydrogen and oxygen to create electric power and water. Unlike diesel engines, they produce little pollution. Another feature is that they can achieve electric energy conversion efficiencies well in excess of conventional internal combustion engines. In recent years, several fuel cell manufacturers have introduced prototype devices that are intended to meet the low power (3-5 kW) residential market. These devices typically draw the hydrogen from a fuel source such as natural gas (mostly CH_3) or methanol (CH_3OH). Many systems are at the advanced prototype stage and are being demonstrated in real-world applications. A full description of such installations can be found in the most recent 2000 Fuel Cell Seminar Abstracts, (2000 Fuel Cell Seminar).

1.3 Overall Project Objective

Over the past few years, the Coast Guard Research and Development Center has conducted several studies to evaluate the potential of fuel cell technology to support Coast Guard missions. In 1998, the R&D Center received a Request for R&D Support from the Assistant Commandant of Systems (G-S) to assess the performance and costs associated with fuel cells systems. (Letter COMDT (G-SEC), 1998) The project objective was to evaluate the potential benefits of fuel cells for electric power generation, and to evaluate the feasibility of installation in various applications throughout the Coast Guard. Larger fuel cells (over 200 kW) are the subject of an ongoing demonstration project at Air Station Cape Cod and will be reported on under separate cover. The demonstration described in this report covers low-power, remote applications.

1.4 Need for Prototype Demonstration

1.4.1 DOE-NETL Partnership

The decision was made in early 1999 to collaborate with the Department of Energy's National Energy Technology Laboratory (DOE-NETL) to support our evaluation of the potential of fuel cell technology for low power remote applications. DOE-NETL has extensive experience with developing fuel cells and readily agreed to work with the R&D Center. In November 1999, the USCG R&D program signed a Memorandum of Agreement with DOE-NETL, and they provided resources, helping to develop alternative energy systems for the Coast Guard prototype evaluation.

1.4.2 Prototype Evaluation

Based upon discussions with DOE-NETL and CG personnel at the April 2000 Short Range Aids to Navigation Conference, it was decided that a prototype installation/demonstration at an operational site would afford the best opportunity to evaluate the potential of fuel cells in the Coast Guard environment. Issues such as initial cost, operation and maintenance cost, safety, and training were considered to be as important as technical performance. Many optimistic claims by fuel cell proponents were based upon laboratory studies in which environmental factors were eliminated. Only in the real-world setting could a fuel cell system be evaluated.

After review of available sites, the Cape Henry Lighthouse located on the U.S. Army's Fort Story Property in Virginia Beach, VA, was selected as a suitable location for the prototype demonstration. Factors that were considered included the large variations in temperature and humidity expected in Virginia, the ability to provide fuel truck access to the site, the ease of accessing the site by R&D personnel, and the fact that there were on-site Coast Guard personnel.

1.4.3 Technology Selection

Fuel cells are classified by the type of their electrolyte (Hirschenhofet, 1994). Our collaboration with DOE-NETL showed that the most likely fuel cells to fulfill Coast Guard remote low power requirements were either Polymer-Electrolyte-Membrane (PEM) or Molten-Carbonate (MC). These were better-developed systems and several manufacturers were producing prototypes. Other fuel cell technologies were either too expensive, used pure hydrogen as a fuel, or were not as well developed. The use of pure hydrogen presented significant safety issues and hydrogen was not readily available in inexpensive quantities. Consequently, only fuels that were readily available such as natural gas, propane or alcohols were considered.

In early 2000 in response to a R&D Center RFP, Fuel Cell Energy, Inc. (now FCE Inc.) from Danbury, CT, was selected to provide a three kW direct methanol fuel cell based upon its MC proprietary technology. During this six-month evaluation period the fuel cell, provided by FCE, powered a parallel, duplicate lighting system to the Cape Henry Lighthouse.

2 Description of Cape Henry Fuel Cell Demonstration

2.1 Site Description

The Cape Henry site was chosen for a number of reasons. A site was required that was close to the ocean to represent the marine environment, similar to that of a remote lighthouse site. The site also had to include a building that could be used to house all the equipment required. This structure could not have any heat, electricity, or water in it. Further, the site had to be accessible by truck for fuel deliveries and servicing. Cape Henry was chosen because it fit the requirements exactly. The old fuel building, 90 feet from the active lighthouse, that years before was used for oil and then later acetylene storage, was chosen to house this new state of the art power system. Figure 1 shows the site diagram with the ocean to the North.

To prepare the site for the installation, a telephone line was installed to the building. This line would provide the electronic access to the site for monitoring by the USCG R&D Center and Fuel Cell Energy personnel. A deck was constructed to hold the 500-gallon fuel tank, and because it is a historical site the front door was replaced with a new door where holes were cut for ventilation and for a window. Once the installation of the fuel tank was completed, a fence was built around the deck with two doors for access and refueling. Figure 2 shows the fuel building housing the fuel cell with the fuel tank and deck as installed.

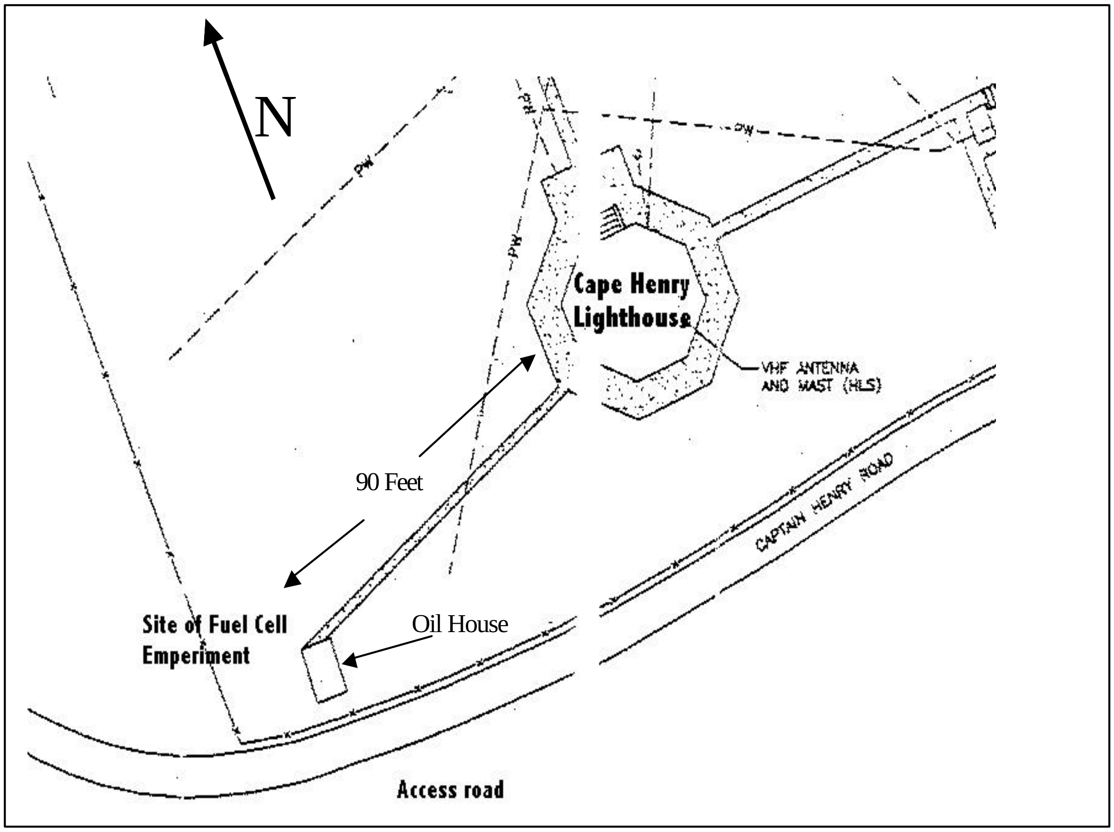


Figure 1. Cape Henry site drawing.

Figure 2. Cape Henry test site with fuel tank.

2.2 Overall System Description

The fuel cell was installed at the Cape Henry site and started operation on 23 February 2002. This date constituted the start of a five-day onsite acceptance test. The five-day factory tests were previously completed and a record of those tests can be found in Appendix B.

The fuel cell is a direct methanol type of molten carbonate fuel cell. Figure 3 shows a schematic diagram of the fuel cell and balance of plant systems. The fuel cell has a footprint of 3 ft. x 4 ft. and is 3 feet high and weighs approximately 1,200 pounds. The maximum power output of the system is approximately three kW. The output voltage of the fuel cell is nominally 36 volts DC. The fuel cell has three moving parts, an air blower which provides air (oxygen) to the system, a fuel pump to pressurize and pump the fuel into the system and a fuel injector. The system requires three gas cylinders for operation, one each of hydrogen, carbon dioxide, and nitrogen. The hydrogen and carbon dioxide were used on startup. It was later determined that the system could be just as easily started on the methanol/water fuel mixture, and the hydrogen and carbon dioxide were removed. To automatically purge the system, the nitrogen was used at shutdown. These gas cylinders were kept inside the building with the operating fuel cell.

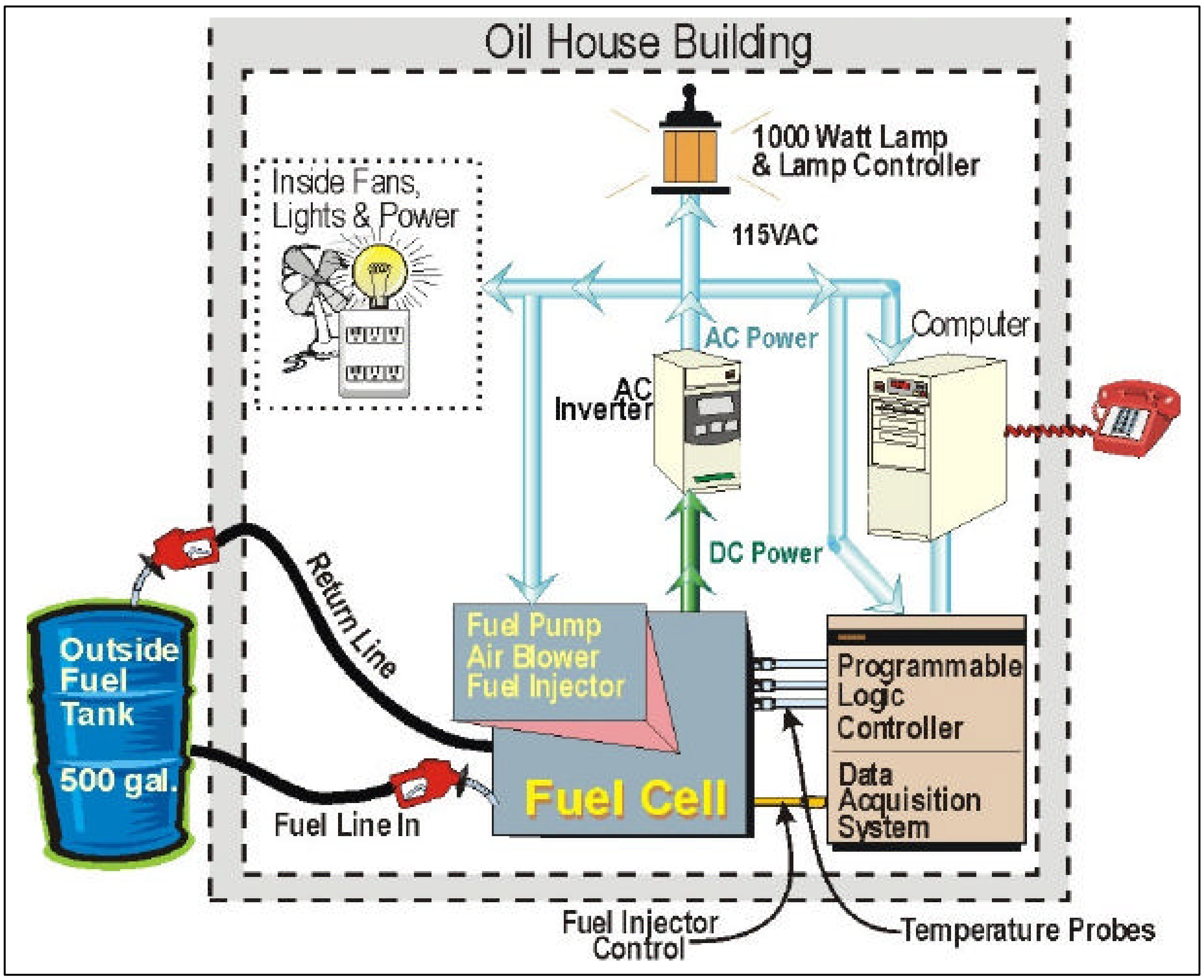


Figure 3. System Schematic of Fuel Cell Installation.

An inverter manufactured by Trace Engineering was used to convert the DC power to 115 VAC power. As a safety control, the inverter, a four kW series SW inverter, was programmed for low voltage cutout of the system.

The electrical load consists of a standard 1000-Watt tungsten light bulb, a Coast Guard dual bulb lamp changer and a Coast Guard Audio-Visual Controller, which controls the lamp flashing sequence. Additional loads consist of the electronic controls, computer and various vent fans.

The system also utilizes a Programmable Logic Controller system (PLC), which takes temperature data from the fuel cell sensors and issues commands to the fuel injector, for both control and shutdown of the system.

An industrial computer was used to take data from the PLC system and display the data in a usable form. This computer was the remote gateway into the system using the dedicated telephone line.

The installed fuel tank was manufactured by Highland Tank of Stoystown, PA. The tank, a 500-gallon above ground vertical, lined steel, double wall, type I-360 tank, meets the UL 142 standards for fuel tanks. The tank was air-pressure tested by USCG personnel prior to actual operation.

2.2.1 System Costs

To properly assess the total cost of this fuel cell system, all aspects of the installation and operation must be considered. The cost of the original contract for this project was $100K. This cost included the five-day factory testing, and the on-site setup and the five-day on-site test, which included travel for FCE personnel and the first fuel delivery of 500 gallons. In support of this project, FCE used no less than an additional 35 staff-days on site. The USCG incurred travel expenses in the order of $16K, and an additional $8.8K for the fuel to be mixed and delivered to the site. Total costs for this project by the USCG and FCE are much more than the original $100K contract. It should be noted that these costs are development expenses. Since this demonstration terminated without proceeding to a commercial unit, there are no data on production unit costs. If this unit were brought to commercialization, it can be understood that the total cost would be that of the original contract or purchase price plus the cost of the fuel consumed, without the additional costs necessitated by a prototype system.

2.2.2 Startup Safety Issues

Prior to the experiment, USCG project personnel met with the U.S. Army Safety and Environmental office representatives from Fort Eustis. Although the USCG owns the property on which the Cape Henry Lighthouse resides, the property is located in the middle of the U.S. Army Fort Story. Safety issues became of prime importance because the USCG was going to transfer the property over to the U.S. Army in the near future. The USCG would however, retain ownership of the aid to navigation (ATON), and associated equipment, and would retain unrestricted right of ingress/egress to maintain or to add or relocate any ATON in order to aid navigation. The safety officer at the parent U.S. Army command at Fort Eustis oversees all safety issues for Fort Story. R&D personnel, the Ft. Story Fire Department Station Chief, Ft. Eustis Safety Officer representative and the Coast Guard Group Engineering Officer attended safety meetings for this test. There were many issues of concern with the fuel, fuel storage and handling system for the fuel cell. The fuel used (47 percent methanol and 53 percent water), being foreign to the Army, was of great concern. Issues raised were concerns about the maximum amount of fuel on station at any given time, refueling, spill prevention techniques, and fuel accounting at the end of the test. All safety issues were met prior to the start of the test. A complete description of these can be found in Appendix C, including a Material Safety Data Sheet (MSDS) for the fuel mixture.

2.2.3 System Startup Operation

The fuel cell start up time is approximately 36 hours. The system is heated up with an external power source, in this case a 5-kW gas generator, which powers the two built-in 750-watt electrical heaters. To prevent stack damage, the fuel cell stack must be brought up slowly, at 25 °C per hour from room temperature to 390 °C. This heating can continue overnight automatically using a temperature controller. It is also important that the fuel cell stack never exceeds a 50 °C temperature difference from one side of the stack to the other. Once the temperature reaches 390 °C, the methanol/water fuel mixture can be added. Once the liquid fuel is added, the system must be monitored continuously until the temperature across the entire stack is above 490 °C. Again, the fuel cell should be brought up to temperature at a rate not exceeding 25 °C per hour and should not exceed a temperature difference across the stack of more than 50 °C. There are no temperature shutdown safeguards in place during this part of the heating process. To limit fuel flow, the stack must be controlled by manually adjusting the fuel using the fuel knob on the flow meter. This part of the process could be automatically controlled or remotely controlled if safeguards were in place. These are typical problems associated with a prototype system.

Once 500 °C is reached, the system can be switched from 'startup' to 'automatic.' The system will run continuously as long as fuel is fed to the system, and does not reach the low (500 °C), or hi (680 °C) temperature shut down points.

The Programmable Logic Control system controls the fuel to the system. The set point temperature for this system is 610 °C. This is the temperature around which the control system will control the fuel. Below this temperature the controller tries to add fuel slowly until this temperature is reached. Above this temperature the fuel is cut back to a predetermined fuel flow as set in the system. A more concise description of the startup and the specific control functions that occur when the burner temperature falls below the 610 °C threshold can be found in Appendix D.

2.2.4 Air/Fuel Operation

Figure 4 is a Block diagram of the fuel cell. This system includes three moving parts, the air blower, the fuel pump and the fuel injector. The air blower furnishes oxygen to the system, the fuel pump supplies fuel to the fuel cell stack; H-1 and H-2 are heat exchangers. An aqueous mixture of methanol is pumped to the stack anodes through internal heat exchangers. Residual fuel from the stack anodes reacts with excess air over a catalytic oxidizer and flows through the cathodes of the stack. The stack exhaust gas exits the unit through several heat exchangers used to preheat the incoming reactant streams.

A manual air control valve is provided for bypassing the air heat exchanger during start-up. A fuel pump and an air blower, both powered by 115 VAC supplied by the inverter, deliver the reactants to the unit. An automotive type fuel injector is utilized to modulate the fuel rate in accordance with load and ambient temperature. In the run mode, the operation is completely automatic. The fuel cell stack generates approximately 36 volts DC. The DC power is supplied to a four kW inverter, which supplies AC power to the pumps, blowers, and to the computer and control equipment. Any interruption of this AC power stops all operation of the fuel cell and shuts down the system. Figure 5 shows a picture of the internal stack without any control electronics hooked up. Figure 6 shows a picture of the fuel cell within its enclosure and 1000 Watt lamp in the building.

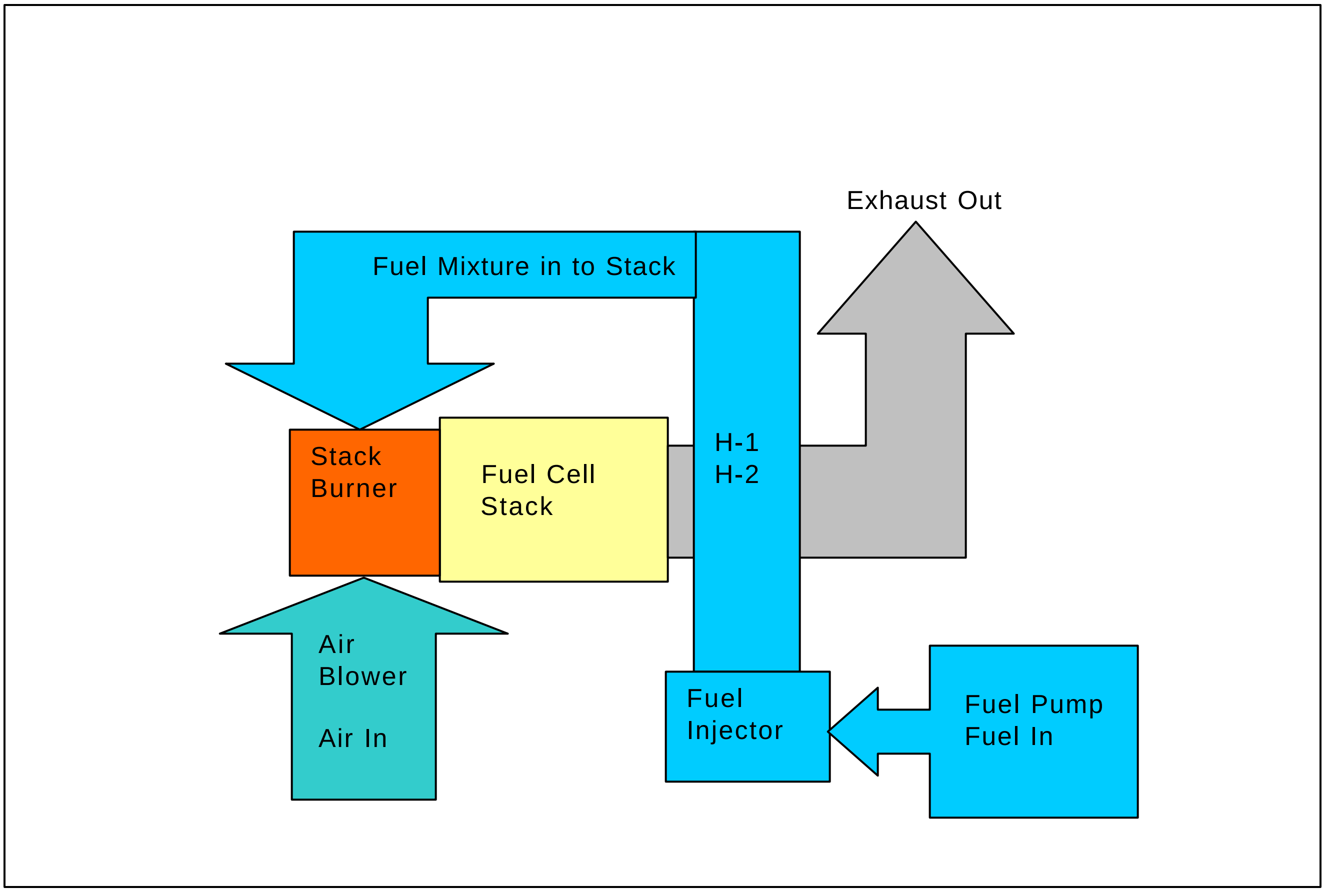


Figure 4. Block diagram of fuel cell.

Figure 5. Fuel cell stack.

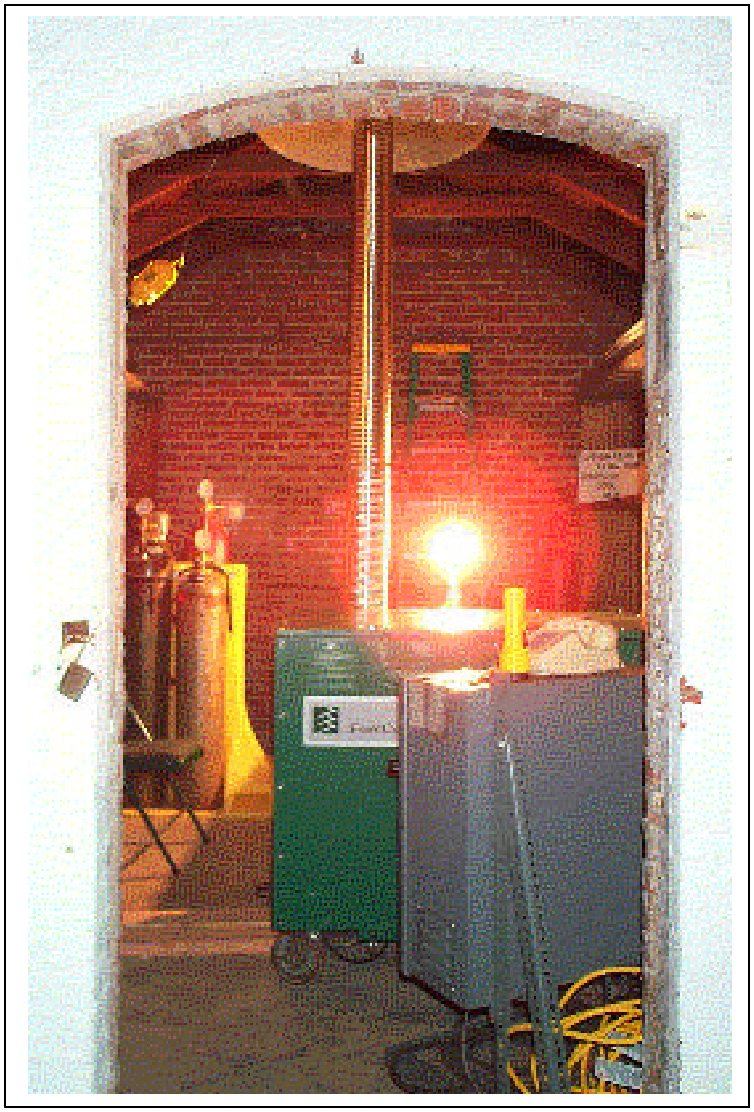


Figure 6. The fuel cell and 1000 watt lamp in the oil building.

3 Six-Month Operational Experience

3.1 Operation

During the five-day on-site test, various temperatures were monitored using an automated data acquisition system (DAS). The main temperature monitored during normal operation is the burner temperature, shown in green on figure 7. Control of the fuel cell, once automatic operation has begun, centers on a burner temperature of 610 °C. The automatic control system keeps the burner temperature at or about 610 °C by adjusting fuel flow through the fuel injector. Figure 7 shows the format of the computer 'Cell Trends' screen available on site and remotely. The screen is a plot of time vs temperature.

Figure 7. Fuel cell temperatures during startup.

The lower left corner shows the date for the plot. This plot starts at 07:34:50 PM on 7/19/2002 and is for 168 hours, concluding at 07:34:50 PM on 7/26/2002. The computer site was password protected and could be assessed only by authorized personnel. The only control function that could be changed is the open time of the fuel injector mechanism, supplying either more fuel by increasing it or less fuel by decreasing it. Figure 7 shows a typical trace of the burner temperature (shown in green), and other temperatures inside the fuel cell stack, as the system is brought up to operating temperature. Figure 8 shows the same temperatures during a period of normal operation around 610 °C. Two additional computer screens were available for diagnostics and viewing. Figure 9 is a sample of the STATUS screen, and displays cell stack (groups of five cells) voltages and the total current in DC Amps drawn from the fuel cell before the inverter, as well as selected temperatures at the moment. This figure shows the fuel injector pulse rate, which isn't available on the cell temperature screen. Figure 10 is a sample of the MAIN MENU screen, which is a block diagram of the fuel cell system with temperatures appended at the appropriate locations. This figure also shows the fuel injector rate in pulses per second.

Figure 8. Cell trends during normal operation.

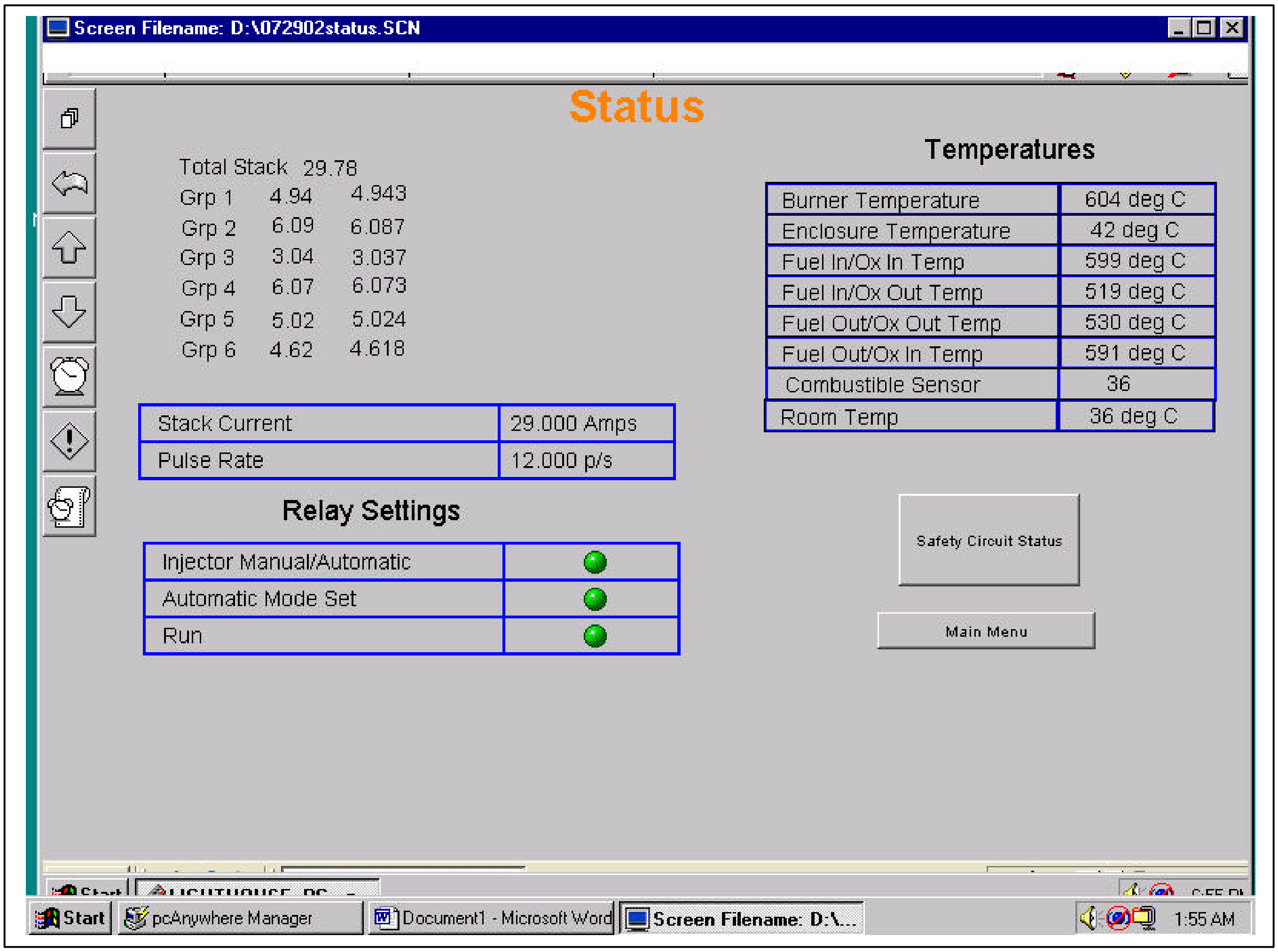


Figure 9. Sample plot of status screen used for diagnostics.

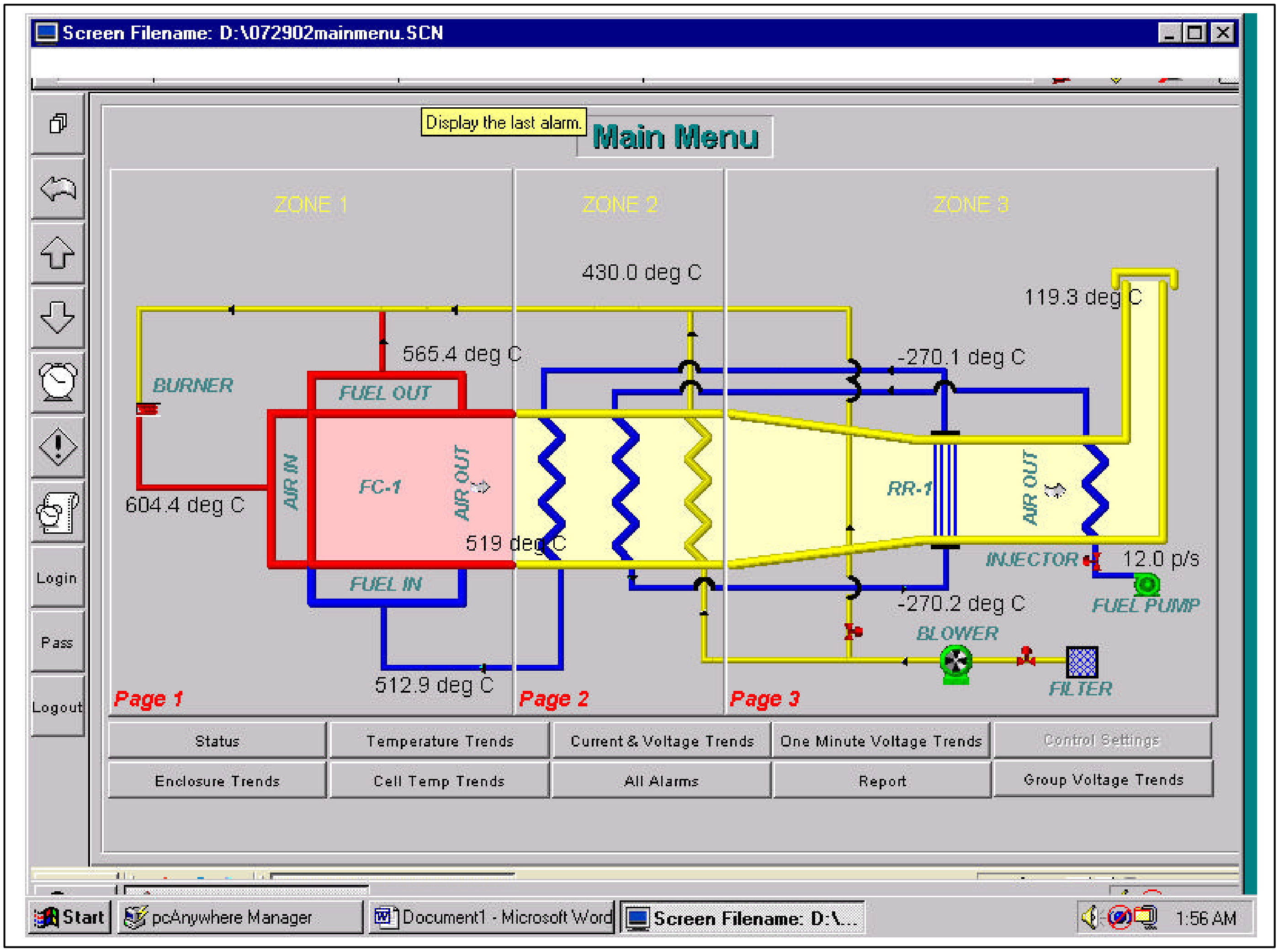


Figure 10. Main menu screen used for diagnostics.

3.2 System Problems and Outages

During the six-month operation of this test system, many outages were experienced. Initially there were multiple problems with the fuel mixture and bubbles within the fuel lines created by the daily heating and cooling of the fuel lines from the storage tank to the fuel cell. In one case, the UPS overheated and shut down due to heat buildup in the building. One of the Programmable Logic Controllers overheated and caused a shut down of the system. One failure was caused by a fuel injector failure in the system. There were two instances of operator errors. All of these failures were overcome and corrected; many were growing pains of a prototype system of new technology. A complete description of these failures can be found in Appendix E. Figure 11 is a screen print showing a low temperature system failure, like that of the fuel injector failure. In all cases, the remote DAS enabled both FCE and the USCG to diagnose problems and expedite corrective action.

Figure 11.   Low temperature shutdown plot.

3.3 System Performance

While the fuel cell started in February, the system suffered start up problems early and the "Official" start date was moved to March 18, 2002. The system ran unattended, except for refueling every 2–3 weeks, or when problems occurred, until September 9, 2002, when a fuel injector failure occurred. This failure was nine days prior to what would have been the end of the six-month test period. It was decided at this juncture to terminate the test rather than repair the fuel injector and restart the test. During the test period, the system operated for 4090.4 hours, and consumed 2,887.8 gallons of the methanol water fuel mixture. Based on 4,752 hours in the six-plus month period, this system was available and producing power 86 percent of the time.

3.3.1 Efficiency Calculations

The efficiency of the fuel cell system was of paramount importance. Fuel cells are promoted as much more efficient than other electrical generating equipment. Table 1 lists all the devices powered by the 115 VAC power supplied by the fuel cell through the inverter and table 2 lists the conversion factors. The total wattage was used to calculate the efficiencies of the system as a whole. Due to the shutdowns that occurred and the 2-3 week intervals where there were no accurate fuel tank measurements, efficiency calculations could not be made at every point during the system operation. Periods of time were selected where there were no interruptions to operation and where accurate fuel measurements were available. Efficiency calculations were made using the conversion factors provided by Fuel Cell Energy personnel.

Table 1. Wattage of devices powered by fuel cell system.

Device	**Current**	**Voltage (AC)**	**Power (W)**	
Monitor	1	115	115	
Computer	4	115	460	
100 Watt bulb			100	
CG Control box	1	115	115	
12 V power supply	1	115	115	
1 KW lamp	4.35	115	500.25	50% cycle
Ceiling Vent Fan			30	
Box Fan			10	
Door Vent Fan	0.78	115	89.7	
Fuel Pump	1.48	115	170.2	
Air Blower	4.7	115	540.5	
PLC Power Supply			60	
PLC Data Acq			345	
Total wattage of devices			**2650.65**	

Inverter efficiency tested at FCE 86%

Table 2. Efficiency conversions and calculations.

Efficiency Calculations – Fuel Cell at Cape Henry

Heat of combustion CH_3OH =		726.6	KJ/gmole
Total Fuel Flow		40.06	g/min
CH_3OH flow		18.8282	G/min
		0.588381	gmol/min
		0.009806	gmol/sec
		7.125297	KJ/sec = KW
AC Power		2.65	kW (total load)
		37.2%	AC Efficiency
For Conversions:			
Usage:			
grams/min	40.061		
gallons/d	16.9421		
gallons/week	118.5947		
gallons/month	474.3787		
time to use 330 gallons=		19.478	days

Using the total wattages from table 1 and the conversion factors from table 2, the fuel use per day was calculated where exact data were available. Using the results, the value of fuel used in grams/minute was calculated. That value was used to compute the overall efficiency of the entire system. The efficiency calculation shown in table 3 is for the overall efficiency, 4090.4 hours and 2,887.1 gallons of fuel used. The following efficiencies were calculated.

Table 3. Efficiency Calculation Results.

Start Date	End Date	Fuel Use Gallons/Day	Fuel Use Grams/Minute	Efficiency Percent
2/24/02	2/27/02	16.535	39.1	38.1
3/8/02	3/9/02	16.21	38.34	38.9
5/9/02	5/28/02	16.64	39.35	37.9
6/18/02	7/08/02	15.91	37.63	39.6
8/13/02	8/27/02	16.36	38.7	38.5
4090.4 hours	2,887.1 gallons	16.94	40.06	37.2

The peak efficiency calculated was 39.6 percent and the overall efficiency calculated was 37.2 percent. For comparison, small diesel generators sized in the 5-kW range are about 20 percent efficient, while diesel generators in the 300 kW size are about 39 percent efficient. The system efficiencies of this fuel cell were good, but there are two conditions that were not included in deriving the efficiency rate; the fuel used to warm up the fuel cell system is not accounted for and the byproduct of heating the building was also not included. While there were no data to support calculations for the heating of the building, we could presume an increase in the efficiency of 5–10 percent to the total if we were able to recover the waste heat productively.

The test ran for approximately 198 days, translating to 4,752 hours. The fuel cell hour meter started at zero hours. The hour meter is only on when the fuel cell is up to normal operating temperature and the inverter is switched on and producing AC electricity. At the end of the test the hour meter had recorded 4090.4 hours. The difference between the actual time from the start to the end of the test and the hours logged by the hour meter for actual fuel cell time generating electricity translates roughly to 661 hours or 27.5 days. This indicates that the system was shut down, warming up or waiting for restart for 27.5 days during that 6.4-month period. Once the system shut down, there was normally less than a two-day period before a restart was in progress. In the beginning when the fuel bubble problem was occurring, the system had shut down for 4-5 days in a row until the problem was solved. During this period restarts occurred each morning, and the latent heat shortened the restart appreciably. Fourteen percent of the time the system was shut down.

4 Conclusions

Over the three-year period from 1999 to 2002, the R&D Center investigated low power remote fuel cell technology. It was determined that fuel cell development for actual field applications is in its infancy. Fuel cells in the three to five kW-size that are fueled by more common liquid fuels are still in an R&D stage of development. During this demonstration of an engineering developmental system, the performance consistently improved as problems with the ancillary equipment were solved. The system operated successfully for extended periods, and was capable of remote unmanned operation while being monitored with remote technical support.

Fuel cells of this size and fuel type are a few years away from becoming commercial items that can be installed and maintained at a site without skilled technical support. This was a demonstration of a prototype fuel cell and is not necessarily indicative of what may happen with a follow-on demonstration at another site. It should not be considered as a valid reliability test of a production or commercial system. Much experience was gained regarding the technology, operation, maintenance and logistics of a field application at a remote site.

In the future, fuel cell power may match USCG needs. It has the potential to provide reliable power to remote sites where other alternative off-grid energy sources are not available. When the fuel cell industry is successful in commercializing reformers to convert diesel fuel, gasoline or kerosene into useable hydrogen for fuel cell applications, then fuel cells will interface well with present Coast Guard logistics. Several fuel cell manufacturers are conducting similar demonstrations for communications towers, parks, and residences where access to grid power is problematic. The capital cost for installation of a commercial fuel cell power system (once they are produced in quantity) should be competitive with diesel systems.

5 Recommendation

The Coast Guard needs to maintain an active role in continuously monitoring and evaluating fuel cell power technology for its remote sites. This is a rapidly changing field and great benefits can be gained by evaluating these systems when they are commercially available. The Research and Development Program within the U.S. Coast Guard is in the best position to conduct this evaluation.

6 Additional Research / Information

Appendix F includes a brief “Economic Analysis of Life Cycle Cost for USCG Remote Site Fuel Cell Power Systems.”

Appendix G includes a “Fuel Accounting to the US Army for the Cape Henry Fuel Cell Project.”

7 REFERENCES

2000 Fuel Cell Seminar (Oct 30 – Nov 2,2000). Fuel Cells Powering the 21st Century (Abstract Publication). Portland, Oregon.

Commandant (G-SEC) letter dated (March 1998). Request for R&D support entitled “Shore Facility Fuel Cell Demonstration.”

Hirschenhofer, Stqauffer, Engleman, (1994). Fuel Cells a Handbook (Report No. 94/1006). Morgantown, WV: Department of Energy, Materials and Energy Technology Center.

Lincoln, Walter (1999). A New Power System for the New Century. System Times, p. 59-62.

APPENDIX A

A.1 Potential Applications for Fuel Cell Power Systems

A.1.1 Aids-to-Navigation (ATON) Stations

The Coast Guard operates over 1,000 aids-to-navigation structures and lighthouses that are powered by commercial utilities and/or diesel generators. All of these stations are unattended and many are in remote areas with unreliable power sources such as grounded submarine cables. Other considerations such as cost, protection of the environment, historical site preservation, and access to an electrical utility may affect power availability.

Table 4. ATON Power Sources from the ATONIS Database.

Solar / battery	15,247
Battery only	177
Primary diesel generator	1
Commercial utility	978
Commercial utility & diesel generator backup	67
Ocean wave	5

Shore power cables are expensive to replace and are likely candidates for alternative power. Several Coast Guard lighthouses, such as Miah Maull in Delaware Bay and Sequin Island in Maine, are on commercial power via submarine cables that have become grounded. Replacement costs for these cables can be as high as $300,000. Alternative power sources require huge solar arrays and/or wind generators with reduced capability that may be unacceptable to local mariners and historical preservation groups. These sites, along with the 68 other sites with diesel generators (primary and secondary), should be considered for direct conversion to fuel cell power depending upon the condition of their existing power systems. The need to deliver fuel to sites formerly powered by electric utilities may meet with some resistance from operational personnel.

A.1.2 National Distress and Response System (NDRS)

The NDRS Database lists 275 VHF-FM High Site short-range coastal communication stations throughout the U.S., and many stations are currently being improved through the NDRS Modernization Project. Part of this project is to upgrade the present power plant that consists of ineffective hybrid battery/PV system/propane diesel systems. Many of these sites are located on islands in remote areas that may be inaccessible part of the year such as Alaska, and fuel cells may be considered as an alternative power source for applications in austere climates. The fuel cell system would run continuously and thereby provide its own waste heat, whereas PV systems are low in power, require huge arrays and are ineffective for much of the year due to short daylight hours in higher latitudes. Three Alaska sites have been identified as possible candidates for installation of fuel cell power: Cape Gull, Sitkinak Dome, and Marmot Island.

A.1.3 LORAN and Radio Navigation Stations

The Coast Guard operates several LORAN stations in remote areas. These stations are under a recapitalization program that includes station upgrading to solid-state electronics, automation, or a reduction in manning. These stations require a variety of sizes of power systems, ranging from a few kilowatts for monitoring sites to several hundred for a major transmitter site. The main requirements are clean, noise-free premium power for the sensitive time-based electronics and a reliable, uninterruptible power source. LORAN sites are potential locations to evaluate the long-term reliability of fuel cell power systems.

A.1.4 Differential GPS Stations

Currently, there are about 60 maritime DGPS sites in the United States. Many of these sites are on or near fragile wetlands, and petroleum powered generators were not installed because of the environmental concerns. Remote, unreliable and environmentally sensitive DGPS sites can be provided with electrical power systems that are more efficient, environmentally clean, and more reliable with less maintenance costs. Small fuel cell power systems have the potential to offer a more efficient, environmentally clean, more reliable and less costly source of power. Some of these sites need backup power, and alternatives such as the fuel cell technology provide advantages over traditional diesel generators and are more environmentally acceptable. Fuel cells can also provide a secondary and uninterruptible power supply in the event of failure or damage to the primary power source

A.1.5 Marine Weather Stations

The Coast Guard supports sites in coastal waters for the National Weather Service through the National Data Buoy Center in Bay St. Louis, MS. The system consists of 54 Rohn Tower sites in coastal areas and offshore buoy sites. There are 12 large navigational buoys that replaced lightships and ocean weather stations and about 60 smaller three-meter and six-meter buoys that observe and report weather observations. The present buoy power systems provide about 50 Watt-hours per day, and it is desirable to increase the capacity to transmit more frequent event-driven weather observations and support more sensors. Additionally, an active anti-fouling system can keep the hull clean for longer periods and also requires additional electrical power. More solar panels cannot be used with these buoys due to stability and wind age restrictions. Fuel cell power systems could replace the batteries, and can offer extended periods of relatively maintenance-free operation with increased capability.

APPENDIX B

B.1 CHRONOLOGY of FACTORY TESTS

B.1.1 Five-Day Factory Test #1

The first factory five-day test was scheduled to start on April 16, 2001 in the new FCE plant in Torrington, CT. This test coincided with a plant dedication by the Governor of the State of Connecticut, on April 17th. The fuel cell was started on the morning of the 16th and ran until the morning of April 19th. During this time various changes were made to the control functions of the control system. The Governor visited and dedicated the new manufacturing facility on April 18th. When we arrived on the 19th the fuel cell had shut down. A quick restart demonstrated that the system had shut down as a result of a small fuel leak in one of the manifolds. This test was scratched and the fault had to be corrected.

Once the fuel cell was taken apart and the manifolds were inspected, new thermocouples were installed to sense this situation if it ever recurred. During this period, it was determined that a new stack should be built so that the Coast Guard would start with a completely new system and new safeguards were proposed for the system. Additional programming changes to the control program were also instituted during this period. The physical plates that make up this fuel cell stack are much smaller then the plates manufactured at the Torrington facility for the 250 kW fuel cell power plants. In order to make a new stack, certain welding and manufacturing functions had to be sent out and completed by hand by subcontractors. This caused a substantial delay in the proposed start date at Cape Henry.

B.1.2 Five-Day Factory Test #2

The second factory test was scheduled to start on December 6, 2001 at the Danbury, CT, FCE facility where all the test equipment was housed. The system was started on electrical heaters on December 5th. On December 6th, the fuel (methanol and water) was started into the system at 0900, the system was heated on the mixture and at 1444 the load (USCG 1000 watt flashing lamp and associated equipment), were powered up and running. At 1500 the load was turned off due to a low voltage indication, and the stack was allowed to cool down for further inspection, as a precautionary measure. The inspection revealed no carbon build up in the manifold, and no immediate problems. It was thought that some of the cells maybe flooded with electrolyte and that may have caused the low voltage. A new five-day test was scheduled for January 10, 2001.

B.1.3 Five-Day Factory Test #3

The third factory test, at the Danbury, CT, facility commenced on 10 January 2001, when the electrical heaters were turned on. At 0940 on the January 12th, fuel was added and heating continued. At 1641 the inverter was turned on using only the housekeeping load and the lamp was off. Shortly it became evident that the automatic temperature control was causing large temperature swings in the burner temperature. The fuel injector control settings were adjusted for on time and frequency but were not adequately controlling the system. The system was again shut down on December 13, 2001. It was obvious that the control system, which monitors various temperatures within the fuel cell and issued commands to the fuel injector for heat and load were not optimized at this point. It should be noted that this is a prototype system and Fuel Cell Energy did not have many hours prior to this contract operating this system. When it was on, it had always been under the scrutiny of the project personnel and had only been run for a day at a time, in spite of the long warm up. Since the system was being used in a laboratory setting, automatic control functions were only honed for that use.

B.1.4 Five-Day Factory Test #4

The fourth test at the Danbury laboratory commenced on January 22, 2002. The fuel cell controlling software had been reprogrammed and tested; in fact, the fuel cell had been running for 400 hours prior to this test. It was agreed that the fuel cell would be put on heaters prior to our arrival and was warmed up to 410 °C. At 0910 on the 22nd, fuel was started and heating continued until the entire fuel cell stack reached 550 °C. At 1305 the inverter was turned on and the fuel cell was allowed to run with this housekeeping load to stabilize the system. At 1331 the load (1000 watt flashing lamp and equipment), was connected and switched to automatic control. At 1337 on 22 January 2002 the 5-day test was started.

The temperature around which the system controls the fuel is 610 °C, the ‘set point’. During the test, the burner temperature fluctuated between 600 °C and 612 °C, which is a normal range. During the five-day test, an additional load of 700 watts at 115 VAC was added to simulate what would happen when the fuel transfer pump was energized for refueling at the Cape Henry site. The fuel cell generated the additional load with no negative effects to the system. At 1039 on 28 January 2002 the test was successfully completed and the fuel cell was shut down.

B.1.5 Five-Day On Site Compliance Test

USCG personnel prepared the Cape Henry site by running a telephone line into the building, and a deck was built outside the building to support the 500-gallon fuel tank. The tank was delivered and pressure tested to check the double wall containment. It should be noted that the building is considered a historic site so no permanent changes could be made to the structure.

The installation started on February 19, 2002. The fuel cell and equipment were transported to site by truck by Fuel Cell Energy. The installation personnel included four people from Fuel Cell Energy and one person from the USCG R&DC. The U.S. Army was on hand with a forklift and personnel to lift the 1,200 lb. fuel cell off the truck and insert it into the building through the doorway. The doorway molding and door were removed. A new door was built to fit so additional venting of the building could be accomplished.

The fuel lines were hooked up to the fuel tank and the first delivery of 500 gallons of the fuel mixture (methanol 47 percent by wt., deionized water 53 percent by wt.) was delivered in two 250-gallon totes. Emergency response personnel and equipment from the Ft. Story fire department were on hand to observe and as a precautionary measure, as well as a Safety Officer’s representative from Ft. Eustis. The fuel cell electrical heaters were energized using an auxiliary gas generator outside the building. The generator was also used to power lights and tools during the installation.

On February 23, 2002 the fuel cell was started. A new mechanical hour meter was installed into the control panel and set to 0.0 hours so there would be no mistakes made with operating hours during the test. At 1735 on February 23, 2002 the load was turned on and the system was operating autonomously.

On February 26th, the system exhibited peculiar patterns in the burner temperature. The problem was perceived to be a fuel pump problem and the fuel pump was replaced while the system was running. On March 2, 2002, the five-day on site test was considered a success.

All personnel from Fuel Cell Energy left on 3 March 2002, and the R&DC representative stayed to monitor the system one more week.

APPENDIX C

C.1 IMPLEMENTATION ISSUES

C.1.1 Cape Henry Site Pre-Installation Safety Issues

The Cape Henry Lighthouse site was chosen because of its proximity to the ocean which is about 200 yards and because it offered a small building that could replicate and be treated as a remote site; an optimum site representative of the typical Coast Guard marine environment. The building chosen was the original fuel storage building for the lighthouse. The building is 10 x 15 ft, made of double wall brick with a wood roof, and has no heat, electricity or water, has natural ventilation and was accessible by road for refueling.

Although the U.S. Coast Guard (USCG) owns the property on which the Cape Henry Lighthouse resides, the property is located in the middle of the U.S. Army Fort Story. The USCG would, however, retain ownership of the aid to navigation (ATON), and associated equipment, would retain unrestricted right of ingress/egress to maintain and/or to add or relocate any ATON in order to aid navigation. Safety issues became of prime importance in setting up this site for the fuel cell project. The safety officer at the parent U.S. Army at Fort Eustis oversees all safety issues for the Fort Story. R&D personnel, the Ft. Story Fire department Station Chief, Ft. Eustis Safety officer representative and the Coast Guard Group Engineering Officer attended safety meetings for this test. The following issues were of concern.

1) Review what the system consists of, how the system will work, do a quick walk-through of the proposed site and confirm the maximum amount of methanol (and any other hazmat) on hand in any given day.
2) Discuss fuel, fueling and set up a data collection system so that the USCG/fuel cell operators can provide info as to how much methanol is used each day that the system is operated.
3) Determine what fuel/exhaust releases would occur during normal operations and calculate how much is released to each respective media including by-products.
4) Discuss spill prevention techniques and ensure a system is in place where the fuel cell owner/operator understands installation policy regarding spill/leak response requirements. When will the system be operational?
5) It is the responsibility of the U.S. Coast Guard to prevent spills and leaks of methanol that may affect U.S. Army property as well as the health and safety of its soldiers, employees and dependents. Furthermore, our installation policy requires the immediate notification of the Fort Story Fire & Emergency Services Division (422-7456) should a release occur (as directed by the U.S. Army Transportation Center Integrated Contingency Plan and the Fort Eustis/Story Hazardous Materials & Waste Management Standing Operating Procedures). Additionally, the U.S. Coast Guard is responsible for any clean-up/ remediation (to include disposal of waste) and associated costs. All wastes generated by this operation must be disposed of through the Fort Story Hazardous Waste Accumulation Site in accordance through the Fort Eustis/Story Hazardous Materials & Waste Management Standing Operating Procedures.

Items 1, 2, & 3 are based on Fort Story's requirements to document and report (if deemed necessary) the use of a chemical "Toxic Chemical Release Inventory" as required by the Emergency Planning and Community Right to Know Act.

A walk-through was conducted with the Fort Eustis Safety Officer representative, the Fort Story fire station Chief and employees before and during the installation of the fuel cell. The fire station chief and employees were also present during the first fueling to witness our handling of the fuel.

C.1.2 Startup Procedure:

The main power switch was placed in the "startup" position; the blower, fuel pump and fuel injector were turned off on the PLC front panel.

The fuel cell is warmed up using the two built-in 750-watt electrical heaters. These heaters must be powered by an external source; in this case a five kW gas generator was used. This complete warm-up from a cold condition takes about 36 hours. These electrical heaters are controlled by an external controller, which is set to warm the fuel cell up at a rate of 25 °C/hour.

At 390 °C, the fuel mixture is introduced by turning on the blower, the fuel pump and the fuel injector. The fuel injector switch is set to manual. The fuel rate knob on the fuel flow meter controls the fuel injector in manual control.

Three temperatures are monitored during this final warm-up process, the burner temperature, and thermocouples labeled #18k and #190. The fuel cell must be warmed up at a rate not to exceed 25 °C/hour and not to exceed a temperature differential across the fuel cell of more than 50 °C. to avoid excessive thermal expansion. These temperatures are controlled by the fuel flow, and regulated by the knob on the flow meter. The system cannot be left unattended during this part of the warm-up.

At 500 °C, the inverter can be turned on to generate AC power; however, thermocouples #18k and #190, which are on either ends of the fuel cell stack, must both be above 490 °C for this to occur. The main power switch previously set to "startup" controls the power from the generator and or the fuel cell inverter. At the 500 °C point the system can be switched from generator power to the fuel cell inverter power by switching from startup to run. The fuel injector must be switched to automatic control using the switch on the PLC panel, and the fuel rate knob on the fuel meter must be opened all the way so it no longer restricts fuel flow. The fuel cell system is now in automatic control. The fuel cell system (computer, PLC, fuel pump and blower) is powered by the AC electricity supplied by the inverter. As long as fuel is fed to the system, it will continue to generate power. The external generator can now be turned off. The USCG lamp and lamp assembly are powered up by a switch inside the audiovisual controller box, and the entire system is operational and running independently.

C.1.3 Fuel Related Items

The fuel used in this test is a mixture of 47 percent methanol by weight with the balance 53 percent deionized water. The specific gravity of the mixed fuel is required to be 0.921 at 25 °C. Although this fuel is mostly water it must still be treated as a hazardous material. The Material Safety Data Sheet for the fuel mixture can be found at the end of this section. As a note of reference, one gallon of diesel fuel includes the same number of BTUs as approximately 2.25 gallons of pure methanol.

The fuel was delivered premixed in 250-gallon totes, and was supplied by CHEMSOLVE of Roanoke, VA. The fuel connection to the tote consists of a flexible hose and camlock fitting. The fuel was pumped off the truck using an electric fuel pump powered by the fuel cell, and hard plumbed into the fuel tank using a ¾ inch stainless steel pipe. The fuel hose has a cam-lock type fitting which mates with the tote fitting so there is no drip or fuel loss; it is piped directly into the tank. All tank openings are on the top of the tank. The fuel tank is fitted with a leak detection float system within the double-wall which will show any small volume leaks from the inside main tank through the double-wall safety wall. The tank is painted white to help prevent heating in the summer months. A larger opening on the top of the tank is used for periodic manual fuel measurements. These measurements are made using a wood dipstick and noted to the nearest ¼ inch. Throughout the six-month test, a record was kept of fuel deliveries and fuel level readings. Before a fuel delivery was accepted a sample was drawn off into a graduated cylinder and the specific gravity and temperature was tested for quality assurance.

C.1.4 Normal Fuel Cell Operation Releases and Byproducts

The normal mean operating temperature of the fuel cell is approximately 610 °C. The chemical reaction between the fuel-air mixture that takes place in the fuel cell plates is:

$$CH_3OH + 2H_2O = 3H_2 + CO_2 + H_2O$$

Reforming of the fuel is done with a copper/zinc catalyst, operated at 2900 space velocity, or volume changes/hour at full load at O °C. When the fuel cell is operating normally, the average emissions are:

Table 5. Average Daily Emissions.

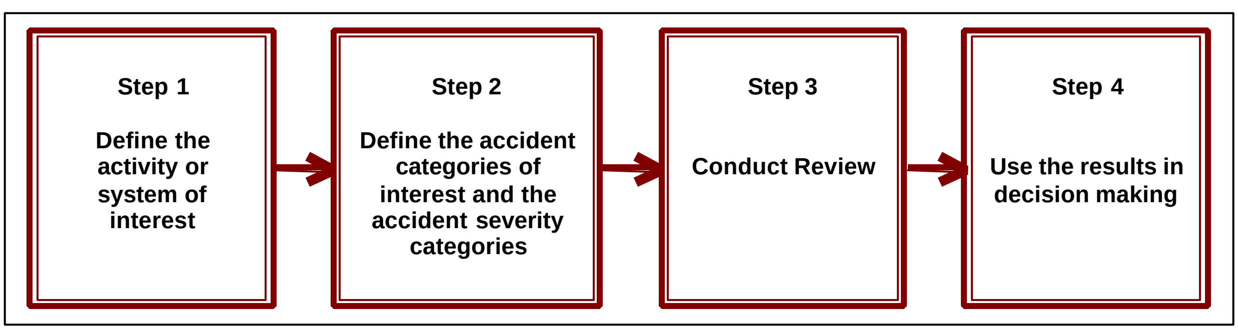
Component	**Ft^3/day**
H_2O (steam)	1900
CO_2	550
O_2	6800
N_2	2850

Dioxin emissions are an important consideration for the safety officer. A letter was generated at by Fuel Cell Energy to the Safety Officer at Fort Eustis affirming that there were no dioxins included in the exhaust.

C.1.5 Spill Prevention and Safety Systems

At the onset of the project, the R&D Center decided to do a Risk Analysis (Preliminary Hazard Analysis), to identify potential problems. The risk assessment team was comprised of the two people from the fuel cell project at the R&DC, the three primary counterparts from Fuel Cell Energy responsible for this project contract, and two subject matter experts (fire and test personnel) from the R&DC and two facilitators from the R&DC.

Procedure for Preliminary Hazard Analysis (PHA)



The top three identified hazard/accident scenarios were associated with an internal fuel leak during routine operation of the fuel cell. The types of fuel-leak accidents are:

1. An internal gaseous fuel (H_2/CO) leak caused by a gasket or seal leak resulting in a fire accident. This scenario was assigned an accident severity category of one (mostly hazardous). Hydrogen is an explosive hazard.

2. An internal liquid fuel (CH_3OH/H_2O) leak caused by a gasket or seal leak resulting in a fire. This scenario was assigned an accident severity category of two.

3. An internal vapor (CH_3OH/H_2O) leak caused by a gasket or seal leak resulting in a fire accident. This scenario was assigned an accident severity category of two.

Addressing all the safety issues cumulatively, the following safety precautions were taken or are part of the fuel cell system.

The actual lighthouse at Cape Henry is an operational lighthouse and the maritime community relies on that light remaining lit. It was decided early on that because this is a prototype system with unknown reliability, that a duplicate light would be powered inside the oil building and not the actual Cape Henry light.

The fuel tank is a double wall tank with a UL rating of 142, which is required for this application. This fuel tank is compliant with NFPA 30. The tank has a built-in visual leak detection system. The tank interior is coated with Ultra liner coating SP-6, and was painted white to reduce heating of the fuel.

The stainless steel fuel line running along the ground to the fence was taped with yellow caution tape. The fuel tank was labeled exactly as the totes to alert others of the exact contents of the tank. The fuel tank was enclosed in a fence with two doors, which allowed immediate access to the tank and valves. The fence was labeled with no smoking signs and a sign designating the site as a USCG R&D project, including phone number. The front door of the building is labeled with the same USCG R&DC sign, and with a sign to call 911 in case of emergencies.

An emergency fuel shut off valve was installed outside the building in the fuel line near the tank and marked. An emergency shutoff switch was installed inside the building just inside the door, which shuts off the fuel injector and cuts fuel to the fuel cell. A CO and CO_2 sensor was installed inside the building in plain view of anyone entering to alert them to adverse conditions. An appropriate fire extinguisher is mounted on the wall just inside the door.

The inverter was programmed to shut down at a low input voltage cutoff of 22 VDC, this cuts all 115 VAC, which powers the fuel pump, blower and all control equipment, shutting off fuel to the fuel cell.

Temperature sensors in the fuel cell system shut the system off at a high temperature cutoff of 680 °C. Normal operating temperature is around 610 °C. Temperature sensors in the fuel cell system shut the system off at a low temperature cutoff of 500 °C, which may indicate a manifold leak in the system.

A combustible gas sensor inside the fuel cell enclosure will trip the plant if the reading reaches the trip point. A complete copy of the USCG risk assessment and an MSDS for the fuel was forwarded to the Fort Story fire station chief, Operations officer (this was the USCG R&DC contact for this project), and to the Fort Eustis Safety officer, prior to the start of the project.

The first fueling of the fuel cell on 2/21/02 was witnessed by personnel from the Ft. Eustis safety office, the Ft. Story Fire Department, and all concerned with the fueling process and safety of this project. Fire trucks and safety equipment were on hand as a precaution. An inspection of the premises, power plant and associated equipment concluded in a stamp of approval by all concerned. The fire chief requested that the fire department be notified when future re-fueling would take place.

The system start-up would begin on 2/22/02, and become operational on 2/23/02. Note: the following figure shows a safety chart developed by Fuel Cell Energy of possible problems and the system response to each.

What-If Scenarios

Issue	Cause	Consequences	Safety Response
Fuel Delivery Failure	Pump Failure, Injector Plug/Fails Closed, Fuel Leak, Fuel Filter Failure, Tank Leak, Empty Tank	Burner Temperature reaches low set point, Stack voltage drops	System trips on Burner Low Alarm, goes to automatic shutdown. Inverter trip at Low Stack Voltage. Combustible gas detector senses high shuts system down.
Fuel Over-Delivery	Injector Fails Open, PLC Control Failure	Burner Temperature reaches high set point.	System trips on High Burner Alarm. Stack temperatures reach high alarm, trips system. Enclosure temperature alarm limit reached, trips system.
Loss of Air Flow	Blower Failure	Burner Temperature reaches low set point, Stack voltage drops	Same as Fuel Delivery Failure
Loss of Inverter	Inverter Failure, Power Line failure	Blower, Fuel pump, Light shut down, stack voltage drops	Automatic Shut Down
Localized Fuel Leak in Power Plant	Stack Manifold Failure	Burner temperature drops to low set point. High set point reached in manifold TC's	Shutdown activated on low burner temperature and/or high manifold temperature.

FuelCell Energy

C.1.6 Responsibilities of Hazardous Materials

A letter from the Office of the Garrison Commander, E. Douglas Earle, Colonel, Department of the Army, dated 1/29/02, addressed to Mr. Walter Lincoln USCG R&DC outlining the USCG's responsibilities. The USCG R&D Center acknowledged the responsibility for the usage and handling of hazardous materials within the Coast Guard property and within the U.S. Army compound.

C.2 MSDS Methanol 47 percent, Water 53 percent Mixed by weight.

MATERIAL SAFETY DATA SHEET

Section 1. Product and Company Information

Product Name: Methanol Solution

Manufacturer: Fuel Cell Energy, Inc.
3 Great Pasture Road
Danbury, CT 06813

Phone: 203-825-6000

Fax: 203-825-6100

Section 2. Composition / Information on Ingredients

Component	CAS Number	Percentage	Exposure Limit
Methanol	67-56-1	47	200 ppm PEL-TWA 200 ppm TLV-TWA skin 250 ppm STEL-TLV
Water	7732-18-5	53	None Established

Section 3 Hazards Identification

This product is a clear, colorless liquid with a mild alcohol odor.

Emergency Overview
Combustible liquid and Vapor! May cause eye irritation. Inhalation may cause headache, dizziness, drowsiness, nausea, visual impairment, acidosis, narcosis and unconsciousness. Methyl Alcohol may be absorbed through the skin in harmful amounts. Poisonous if swallowed.

Section 4 First Aid Measures

Eyes: If contact occurs, immediately flush eyes with plenty of water for 15 minutes. Hold eyelids open to assure thorough flushing. Get medical attention.

Skin: Remove any contaminated clothing. Immediately wash contact area thoroughly with soap and water. Launder contaminated clothing before re-use. Get medical attention if irritation or symptoms develop.

Ingestion: Get immediate medical advice by calling a Poison Control Center, or hospital emergency department. Do not attempt to give anything by mouth to or induce vomiting to an unconscious or drowsy person.

Inhalation: Remove person to fresh air. If breathing has stopped administer artificial respiration. If breathing is difficult, have medical personnel administer oxygen. Get immediate medical attention.

Section 5. Fire Fighting Measures

Flash Point: 75 °C (167 °F) ASTMD93
Explosive Limits: LEL: 6.0 percent (methanol) UEL: 36 percent (methanol)
Auto ignition Temperature: 867 °F (464 °C) (methanol)

Extinguishing Media: Use carbon dioxide, alcohol foam or dry chemical. Do not use water to extinguish fire. Cool fire exposed containers with water.
Unusual Fire and Explosion Hazards: Combustible liquid. Methanol-water mixtures will burn unless very dilute. Flame is invisible in daylight. Vapours are heavier than air and may travel to remote ignition sources and flashback. Vapours may form explosive mixtures with air.
Special Fire Fighting Procedures: Wear positive pressure self-contained breathing apparatus and full protective clothing.
Hazardous Combustion Products: Burning may release carbon monoxide, carbon dioxide and formaldehyde. Contact with metals such as aluminium may produce flammable hydrogen gas.

Section 6. Accidental Release Measures

Wear appropriate protective clothing and equipment. Eliminate all ignition sources. Ventilate area. Contain spill and collect with an inert absorbent and place into a suitable container for disposal. Do not use combustible materials such as sawdust. Do not flush to sewer. Notify authorities as required. Refer to Section 8 for personal protective equipment.

Refer to Section 13 for disposal information.

Section 7. Handling and Storage

Handling: Avoid contact with eyes, skin or clothing. Avoid breathing vapours or mists. Harmful or fatal if swallowed. Use only with adequate ventilation. Wash exposed skin thoroughly with soap and water after use. Do not swallow. Remove contaminated clothing and launder before re-use. Keep away from heat sources, sparks, flames and all other sources of ignition. No smoking in use or storage area.

Empty containers contain product residues and may be hazardous.

Storage: Store in a cool, well-ventilated area away from heat, sparks, open flames and all sources of ignition.

Section 8. Exposure Controls / Personal Protection

Exposure Limits: Refer to Section 2.

Engineering Controls: For operations where the TLV may be exceeded, mechanical ventilation such as local exhaust may be needed to maintain exposure levels below applicable limits.
Respiratory Protection: For operations where the TLV may be exceeded, a NIOSH approved supplied air respirator or positive pressure self-contained breathing apparatus is recommended. Organic vapour cartridge respirators are not recommended for methanol vapour exposures. For fire fighting, use self-contained breathing apparatus. Respirators should be selected and used in accordance with all applicable regulations (in the US, OSHA 1910.143) and good industrial hygiene practice.
Eye Protection: Splash-proof goggles recommended.
Skin Protection: Chemical resistant gloves such as butyl rubber or Viton where contact is possible. Wear appropriate protective clothing to prevent skin contact.
.

Section 9. Physical and Chemical Properties

Appearance and Odor: Clear, colorless liquid with a mild alcohol odor. The reported mean odor threshold for methanol is 160 - 690 ppm.

Solubility in Water:	Complete	**Boiling Point:**	149 °F (methanol)
pH:	Not Available	**Melting Point:**	-144°F (methanol)
Specific Gravity:	0.9	**Vapor Density:**	Greater than 1
Evaporation Rate:	Not Available	**Vapour Pressure:**	Not Available
Partition Coefficient:	Not Available	**Flash Point:**	75 °C

Section 10. Stability and Reactivity

Stability: Stable.
Incompatibility: Avoid heat, sparks, open flames and all other sources of ignition. Incompatible with strong oxidizing agents, strong acids and zinc, aluminium and magnesium.
Hazardous Decomposition Products: Burning or heating to decomposition may release carbon monoxide, carbon dioxide and formaldehyde.
Hazardous Polymerization: Will not occur.

Section 11. Toxicological Information

Health Hazards

Inhalation: Vapours or mists may cause irritation of the nose and throat with headaches. High vapour concentrations may cause headache, dizziness, drowsiness, nausea, vomiting, tingling, numbness and shooting pains in the hands and forearms and visual disturbances.

Skin Contact: Prolonged skin contact may cause redness and defeating of the skin. Methanol may be absorbed through the skin with symptoms similar to those listed under ingestion.

Eye Contact: Liquid, vapors or mists may cause irritation with redness, tearing and temporary corneal damage.

Ingestion: Methanol is highly toxic and may produce severe acidosis, blindness and death. Swallowing may cause abdominal discomfort or pain, nausea, vomiting, dizziness, drowsiness, headache, visual disturbances, convulsions, coma and death. Visual effects from methanol include blurred vision, double vision, changes in color perception, restriction of visual fields and complete blindness.

Massive overdoses of methanol may cause damage to the liver, kidney and heart muscle. There may be a delay of several hours between swallowing methanol and the onset of symptoms. Toxicity is related to the degree of acidosis produced during the time between exposure and treatment. Swallowing as little as 4 ml of methanol has caused blindness and ingestion of 80-150 ml is usually fatal.

Chronic Hazards: Prolonged or repeated inhalation exposure may produce signs of central nervous system effects, including nausea, vomiting, headache, dizziness and visual disturbances. Prolonged overexposure at levels of 800-1000 ppm may result and in severe eye damage. Repeated skin contact may cause dermatitis.

Cancer: None of the components are listed as a carcinogen by IARC, NTP or OSHA.

Mutagenicity: Methanol has been positive in bacterial and mammal cell assays.

Reproductive Toxicity: Methanol has been shown to cause embryofetal toxicity and birth defects in laboratory animals.

Medical Conditions Aggravated by Exposure: Individuals with preexisting eye, skin, liver and kidney disorders may be at increased risk from exposure.

Acute Toxicity Values: Methanol: LD50 Oral Rat 5,628 mg/kg;
LC50 Inhalation Rat 64,000 ppm/4hr,
LD50 Skin Rabbit 15,800 mg/kg

Section 12. Ecological Information

Methanol: TLM 96: >1000 ppm

Section 13. Disposal Considerations

Dispose of product in accordance with all local, state and federal regulations.

Section 14. Transport Information

Transportation Classification: Combustible liquid, n.o.s. (contains methanol), 3, NA1993, PG III

Note: Refer to 49CFR 173.150 for exceptions for combustible liquids. Containers of greater than 10,638 lbs. must be identified as RQ.

Section 15. Regulatory Information

OSHA: Hazardous by definition in Hazard Communication Standard (29 CFR 1910.1200). Category: Irritant, Target Organ Effects, Flammable

EPA SARA Regulations:
Hazard Category for Section 311/312: Acute Health, Chronic Health, Fire

Section 313 Toxic Chemicals: This product contains the following chemicals subject to SARA Title III Section 313 Reporting requirements:

Methanol	47 percent

Section 302 Extremely Hazardous Substances (TPQ): None

Toxic Substances Control Act (TSCA): All components of this product are listed on the TSCA inventory.

CERCLA Section 103: Methanol has a RQ of 5,000 lbs. Releases over the RQ (reportable quantity) must be reported to the National Response Center. . The RQ for the product is 10,638 lbs. Many states have more stringent release reporting requirements. Report spills required under federal, state and local regulations.

California Proposition 65 - This product does not contain chemicals regulated under California Proposition 65.

This product has been classified in accordance with the hazard criteria of the CPR and the MSDS contains all the information required by the CPR.

Canadian Environmental Protection Act: All of the components of this product are listed on the Canadian Domestic Substances list (DSL).

Canadian Workplace Hazardous Materials Information System (WHMIS) categories apply to this product:
D-2-B Irritant, Chronic Toxin,
B-3 Combustible Liquid

Section 16. Other Information

NFPA RATING (NFPA 704) FIRE: 2 HEALTH: 2 REACTIVITY: 0

APPENDIX D

D.1 System Operation

D.1.1 System Startup

The fuel cell start up time was approximately 36 hours. The system was heated up with an external power source, in this case a 5-kW gas generator, which powered the two built in 750-watt electrical heaters. The fuel cell stack must be brought up slowly, at 25 °C per hour from room temperature to 390 °C. This heating can take place overnight with out intervention using a temperature controller. It is also important that the fuel cell stack never exceeds a 50 °C temperature difference from one side of the stack to the other. Once the temperature reaches 390 °C, the methanol/water fuel mixture can be added. Once the liquid fuel is added, the system must be monitored continuously until the temperature across the entire stack is above 490 °C. There are no temperature shutdown safeguards in place during this part of the heating process. The stack must be controlled by manually adjusting the fuel flow using the fuel knob on the flow meter to limit fuel flow. Again, the fuel cell should be brought up to temperature at a rate not exceeding 50 °C per hour and should not exceed a temperature difference across the stack of more than 60 °C.

Once 500 °C is reached, the system can be switched from 'startup' to 'automatic' and the system will run continuously as long as fuel is fed to the system, and it does not reach either the low (500 °C), or hi (680 °C) temperature shut down points.

D.1.2 PLC Control About 610 °C

The PLC controls the fuel to the fuel cell system. The set point temperature for this system is 610 °C. Below this temperature, the PLC adds fuel slowly until this temperature is reached, above this temperature the fuel is cut back to a normal fuel flow as set in the system. When the burner temperature is below 610 °C the following controls are added to the fuel injector to bring the system up to temperature:

1- Normal operation is in 200-second increments where the fuel injector is operated for 4 out of every 10 seconds at preset control conditions. For example 12 pulses per second with an on time of 14 milliseconds would be a typical starting point.

2- If during that 200-second period the burner temperature does not reach 610 °C, the second cycle starts and continues for 350 seconds. During this 2nd cycle, the same timing occurs but for the first two seconds of each 10-second period, one additional pulse is added to the fuel injector.

3- If during that 350-second period the burner temperature does not reach 610 °C, the third cycle is started for a time of 40 seconds. During this time the same single pulse is added for the first seven seconds and returns to the original pulse rate for the next 1 second, repeating every 8 seconds. If the 610 °C set point in not reached during this time, it will stay in this control pattern in 40-second intervals until 610 °C is reached and be reset to the first cycle.

4- If during any of the above cycles 610 °C is reached, the system resets to the first cycle.

APPENDIX E

E.1 System Start Up Problems & Power Outages

E.1.1 Air bubbles in fuel line

On 2/3/02 the system shut down due to an over temperature spike. There was no apparent cause for this to happen. The system shuts down if the burner temp reaches 680 °C. The system was restarted on electrical heaters on 3/4/02, and FCE sent an engineer to help. After another failure on 3/5/02, the fuel injector was replaced as a probable cause for the shut down.

On 3/6/02 again the system was shut down in the morning, but restarted quickly due to residual heat. During the day small bubbles were noticed going through the clear flow cube. The flow cube was a monitoring device for the fuel flow. It has a stainless steel ball, which measures the fuel flow to the fuel cell. On 3/7/02 it was found shut down in the morning, and again restarted. This time there were air bubbles in the flow cube at the top.

On 3/8/02 the system was again found shut down, and restarted. That night while watching the system a slight noise was heard and thousands of bubbles were noticed passing through the flow cube over a 5-10 second interval. These bubbles were like those in sparkling water but smaller in size. Shortly after this, the burner temperature climbed to 682 °C. While that normally would have shut the system down, the fuel injector control was switched to manual for a few minutes and then placed back in automatic to prevent shut down. In fact, this over-temp situation was happening every 25 minutes more or less, very periodic, and each time thousands of bubbles were viewed flowing through the flow cube. Checking the fuel lines from inside at the fuel cell to the tank outside, it was determined that the valve packing on the emergency fuel shut off valve outside on the fuel tank was loose. The valve packing was tightened; the lamp portion of the load was turned off for the night and the system left to idle on the housekeeping load. The system was restarted again on 3/9/02.

On 3/10/02 the system was again found shut down in the morning. It was restarted and the load was turned back on at 2038. On 3/11/02, the system had run overnight, and at 1830 more bubbles were seen flowing through the flow meter. The valve was again tightened and the top was packed with pipe compound in case air was leaking into the packing.

On 3/12/02 the emergency shut off valve was removed and a straight pipe was put in its place until a new valve could be found.

On 4/11/02 the USCG Group Engineer found the system shut down. Service personnel arrived on 4/12/02 and the system was restarted and running on 4/13/02.

On 4/15/02 more bubbles were observed, all the fittings along the fuel lines all the way to the tank were coated with RTV silicone to seal them.

On 4/17/02 the system was found shut down in the morning, and it was restarted and running by the end of the day.

On 4/18/02 the system was again found shut down in the morning. On this occasion it was operator error. The air in valve, which is normally choked half way while starting for a short time, was never opened. The resulting air restriction caused a low power condition, which shut the fuel cell down. The system was restarted by 1407. Thousands of micro bubbles showed in the flow cube again on the 18th and an over temp shutdown condition was averted by temporarily switching the fuel injector control to manual, and a few minutes later back to automatic.

On 5/10/02 the bubble dilemma was solved. During normal operation more bubbles were observed passing through the fuel flow meter. These bubbles seemed periodic preceded by a small noise and each time caused a small rise in the burner temperature generating a saw tooth type pattern on the burner temp plot. These temperature lines are normally almost flat. It appeared that the bubbles were being formed in the fuel line from dissolved oxygen. By tapping on the fuel lines, which run along the side of the building and waiting a short period of time, bubbles could be seen passing through the flow meter. This small test determined this was where the bubbles were forming. Like a clear soda bottle full of water sitting in the sun where small bubbles formed on the inside walls of the bottle, small bubbles of dissolved oxygen form on the inside wall of the fuel line. The fuel line starts at the fuel tank in full sun and passes through one of the small air vents in the bottom of the wall into the hot building and then to the fuel cell. The fuel line is small and has a ¼-inch inside diameter and the fuel flow to the fuel cell is low. When the bubbles on the wall get big enough and one breaks loose it acts as a pusher and pushes other bubbles in front of it; much like rain drops on an automobile windshield, where one drop hits another and then another getting bigger with each encounter. These bubbles are captured by the fuel pump (the noise heard) and are subsequently pressurized to 35 PSI by the fuel pump just prior to being released by the opening of the fuel injector. Upon release these fuel bubbles expand and because there are hundreds or thousands of them they act as a small pressure wave and push fuel into the fuel cell system under more than normal pressure causing a burst of temperature in the burner, which can cause an over temperature situation and a shutdown. The periodicity of this phenomenon was due to different ambient temperatures. Depending on the outside temperature, enough bubbles may or may not form fast enough to become a problem, which is why on some days when only a few bubbles formed they were not enough to trigger a shut down.

On 5/13/02 FCE personnel arrived with what we will call a fuel tree to solve the bubble problem. This fuel tree is a ¾ inch stainless steel pipe about seven feet tall. The fuel from the fuel tank enters through a pipe at a distance of about five inches above the floor. The fuel outlet, which delivers fuel to the fuel cell, is taken from about three inches above the floor. This fuel tree is open to the air at the top and is taller than the fuel tank outside**.** The fuel tree level seeks the same level as the fuel tank level, and as bubbles are formed in the fuel line outside, they are released into the fuel tree pipe and simply float to the top and release into the air. The fuel drawn from a lower level pipe on the fuel level tree is always bubble free.

E.1.2 UPS Problem

A very small uninterruptible power supply (UPS) was on the system. The UPS was inserted only to keep the computer running while the system was switched from the start up mode to normal operation run mode. One of the problems faced when the fuel cell was shutting down often at the beginning of the test was that we would always loose the trace on the computer, so there was never an indication of why the system shut down. The file structure for data storage is about 30 minutes. As the system shut down quickly, the traces were always lost because the UPS had only enough power to last about 10 minutes. To rectify the problem, a very large UPS was put in the system to power the computer for almost an hour. This UPS, however, also gave us problems and in two cases, on consecutive days, caused the system to shut down. As it turns out, the large UPS couldn't withstand the high temperature in the fuel cell building. These units are made for air-conditioned computer rooms and not a room that can get to 107 °F. This unit was taken out about the same time as the bubble problem was solved and the small UPS remained for the duration. The file structure for data storage was changed to a shorter time frame to accommodate the 10-minute power cycle of the small UPS.

E.1.3 PLC problem

On 3/17/02 the FCE personnel reported that there were no more bubbles but that the fuel cell had been shutting down each night now with the temp dropping off, rather than the over temperature situation experienced before. FCE suspected the control hardware was the cause of this shutdown. A possible reason for this failure was an increase in outside temperature which resulted in an increase in temperature inside the building. A hair dryer was used to artificially heat the control box to see if heat was the actual problem. This additional heat caused the fuel injector to fail, and failure was due to overheating of one of the several Programmable Logic Controllers that control the fuel cell. This PLC module was replaced on 3/20/02 and a fan was put in the cabinet to keep air flowing through the control hardware box. This hardware failure appears to be due to the component not meeting temperature specifications.

E.1.4 The Fuel Injector Problem

Early during the testing when the fuel cell was shutting down, prior to the knowledge of the bubble problem, the fuel pump and fuel injector were replaced because it was thought these were part of the problem. As it turned out neither were at fault. On 7/20/02, R&DC personnel arrived on site to find the system shut down. A restart was attempted and it was discovered that the fuel injector was not pulsing. The fuel injector and the integrated circuit were both burned out and were replaced. This was a General Motors production fuel injector with a presumed high reliability and should not have failed. The system was restarted on 7/23/02. This constituted the first real equipment failure that was not due to operator error, equipment not meeting our temperature specifications, or learning about the peculiar aspects of the fuel in a first real-world marine environment installation.

E.1.5 Operator Error

Two instances of operator error also resulted in a system shutdown. On one occasion FCE personnel shut down the system while adjusting the injection frequency bandwidth of the fuel injector remotely over the telephone line. These adjustments were made from time to time as the ambient temperature changed over the year. The error occurred while typing in a new number. The software interaction was sluggish and by the time the error was noticed, there was no time to change it before the system exceeded the high temperature set point.

The second instance was during a restart. R&DC personnel left the manual air control choked. This manual control is used to cut down the flow of air for the first few minutes when fuel is first introduced into the system and then returned to the full open position. When left in the choked position, there is not enough airflow to sustain the fuel cell and it shut down by dropping below the low temperature set point.

E.1.6 Computer Problems

Since the beginning of the test the original computer was a problem. The clock in the computer did not keep proper time, and it was constantly being reset. The modem that provided the only gateway to talk to the fuel cell control system remotely was always sluggish and slow. Eventually it was decided to replace the computer with an industrial type with a new modem. As this took place and the FCE personnel talked with the CITEK company about their software they discovered that the Windows 98®, system software has posed this problem when using their software. They had seen this problem before. The system software was upgraded to Windows 2000®, and two modems were installed in the computer. One modem would be used to send out the automatic faxes that the system sends at 1000 daily, as well as the emergency faxes when the system passes through either the high (680 °C) or the low (510 °C) set points. The other modem would be used expressly for communication for remote access by FCE and R&DC. Both of these modems use the single phone line. Once this new computer system was in place, the computer part of the system ran flawlessly and gave instant communications to test personnel.

APPENDIX F

F.1 Economic Analysis of Life Cycle Cost for USCG Remote Site Fuel Cell Power Systems

Life cycle cost is composed of the initial capitalization cost and the operating costs. The capitalization cost of fuel cell power systems is projected to be greatly reduced due to strong commercial development, and the projected operating costs will be less than comparable diesel-generator plants due to reductions in fuel consumption, maintenance and manning. The current contract with Fuel Cell Energy Inc. to install a three-kW fuel cell system in Cape Henry Light is $100,000, and this cost is projected to decrease in the future when production meets the market demand. Several companies are optimistic about achieving an initial unit cost below $1000/kW by 2005.

At many remote sites such as lighthouses, submarine cables (sub cables) provide electric power, but these cables are expensive to buy and install, and require frequent maintenance. In a lighthouse in Delaware Bay it will cost over $300K to replace the cable. A replacement fuel cell power system may cost less than $100K. In similar situations, other agencies have found that fuel cells can provide a better power choice—the National Park Service reports a saving of $47K for its Golden Gate Bridge Concession Building with a fuel cell installation; the City of New York has recently replaced their overburdened Central Park substation power supply with a fuel cell installation and eliminated a expensive underground cable replacement.

The Coast Guard's solar power program has been very successful over the last 20 years, and now major light stations are being converted to solar power. The Graves Light Station in Boston Harbor presently has a 1000-W lamp and the cost to solarize will be about $150K including the cost of labor. This cost does not include the ancillary equipment already in the Coast Guard inventory. Thus, the capitalization costs of solar/PV and fuel cells are similar, but the life cycle cost of fuel cell power systems do not compare favorably due to their need for fuel.

Fuel cell power systems are a very effective alternative for those sites that require greater power than can be provided by solarization, or cannot be solarized due to other constraints such as climate, site size and/or esthetics. Using these figures, the cost advantage of the fuel cell can be simplified to a comparison between replacing/maintaining the cable and annually transporting the fuel. As an example, the First District wants to eliminate submarine cables for ATON sites, as the cost of maintaining the cable boat is prohibitive. The annual cost is $450K-500K, consisting of $200K for the personnel and $250K for work orders for the boat and cable purchases. There are presently 41 submarine cable sites in D1, and the average cost per site for maintaining the cables is $11K/year, or $6K, not including the billets**.** The cost of transporting the fuel includes platform and billet costs. The fuel could be delivered at an annual saving of about $4K per site, over maintaining the submarine cable.

Air pollution is currently “free” in that fines are not levied for exhaust emissions, but could become a cost liability in the future. Additional advantages for a fuel cell system such as inconspicuous installation and operation are offered such as at Seguin Island Light in Maine where local interests engaged Congress to resist the planned solarization. Seguin has a 17,000-ft cable and electric costs are $1800/yr. If a fuel cell were in use, there would be a need to transport fuel to the fuel cell power system. A one-KW fuel cell system would use approx. 1000 gal/year of methanol. The annual cost of the fuel is comparable to the electric utility cost for Seguin, but both fuel and electrical energy costs are currently volatile and this may change in the future.

APPENDIX G

G.1 Fuel Accounting to the U.S. Army for the Cape Henry Fuel Cell Project

A condition set by U.S. Army Fort Eustis, Environmental and Natural Resource Division, Director of Public Works, was that the USCG R&D Center make a full accounting of all fuel brought onto the Fort Story Army Post, and all fuel used during the experiment. This accounting is to ensure there were no spills on the Ft. Story facility and that the only fuel expended was for that of the fuel cell experiment. The following spreadsheet printout is the response sent to that Office. Included along with this document were copies of all fuel delivery invoices and a copy of the invoice by an EPA certified hazardous material removal company for the removal of unused fuel.

Fuel Accounting for Cape Henry Fuel Cell Project 12/2/02

Project officer Robert Desruisseau 860-441-2660

By USCG R&D Center, 1082 Shennecossett Road, Groton CT. 06340

Fuel is 47% methanol, 53 % deionized water, mixed by weight

FUEL USE DURING PROJECT TEST

There were 3,250 gallons of fuel delivered to the Cape Henry Site. The fuel was provided by Chemical and Solvents Inc. Colonial Heights, VA. 804-526-0877. The fuel cell used 2,889.81 gallons generating electricity.

There were no fuel leaks detected nor any fuel spilled during operation. At the end of the project the fuel tank was pumped out by C&M Industries, Inc. Chesapeake, VA. 757-543-8775. Their invoice # 41311 shows that 161.8 gallons were pumped out. Our measurements show 361 gallons pumped out. Mr. William Barnes from the Ft. Eustis, Environmental Office was on site and was notified of the discrepancy.

The visual leak detector system built into the double wall of the fuel tank showed no leaks to the double wall during any part of the test.

Date	Time	Cumulative Hr Meter	Storage Tank Fuel Depth	Tank Leak Detector	Calculation Cal gal/in	Calculated Gal Used	Cumulative Gal Del
2/21/02	fuel del	500 gallons	0	No leak	8.13 gal/in	0	500
2/21/02	13:02	0.0	61.5"				
2/23/02	17:08	0.0		Start test	inverter on		
2/24/02	8:36	15.5					
2/24/02	11:25		4' 11"			20.2	
2/27/02	11:25		4' 4 7/8			69.9	
2/27/02	15:49	94.6					
2/28/02	11:25		4' 2 1/2			89.1	
3/1/02	11:25		48 1/4			107.3	
3/2/02	11:25		3' 10 1/2			121.5	
3/3/02	11:25		3' 8 1/2			137.7	
3/3/02	19:44	189.4					
3/4/02	7:48	189.4					
3/5/02	8:44	189.4					
3/5/02	11:42		3' 7 3/4			143.8	
3/6/02	9:09	203.0					
3/6/02	11:15		3' 6 1/4	No Leak		156	
3/6/02	13:22	203.6					
3/6/02	14:31	204.7					
3/6/02	16:10	206.4					
3/8/02	8:59	238.5					
3/8/02	11:25		3' 3 1/4			180.3	
3/8/02	18:43	242.5					
3/9/02	7:53	255.7					
3/9/02	11:19		3' 1 1/4			196.5	
3/9/02	13:30	261.2					
3/9/02	20:00	267.6					

		Cumulative	Storage Tank	Tank Leak	Calculation	Calculated	Cumulative	
Date	Time	Hr Meter	Fuel Depth	Detector	Cal gal/in	Gal Used	Gal Del	
3/10/02			3' 0"			206.6		
3/10/02	14:08	271.9						
3/10/02	23:04	275.5						
3/11/02	6:04	282.6						
3/11/02	10:31	287.2						
3/11/02	11:25		2' 10"			222.8		
3/11/02	20:54	297.4						
3/12/02	11:25		2' 8"=32 in			239		
3/12/02	11:53	312.3						
	11:30		Calculated	value based	on 3-11 to	3-12 fuel use	eq 2 in per	day
3/19/02	estimated	fuel level 2'8"	7days x 2"/d	eq 14" used				
3/19/02	11:25	EST 32 -14 =	18 in			352.5		
3/19/02		fuel delivery	250 gallons				750	
3/19/02			48 3/4			61.5 + 50" -	18"= 92.3"	
4/4/02	10:12		1' 8 1/2"	No Leak		581.93		
4/4/02	10:43	fuel delivery	250 gallons		8.06 gal/in		1000	
4/4/02	11:17		4' 3 1/2"			92.3 + 51.5-	20.5" =	123.30"
4/12/02	12:28		3' 3"			683.25		
4/15/02	11:00		3' 1/2"			703.51		
4/16/02	15:42		2' 10"			723.77		
4/17/02	7:35	996.1						
4/17/02	11:35		2' 9 1/2"			727.83		
4/18/02	9:47		2" 8 1/2"	No Leak		735.93		
4/18/02	10:35	1002.4						
4/18/02	14:07	1002.6						
4/18/02	14:34	fuel delivery	250 gallons		8.19 gal/in		1250	
4/18/02	15:25		5' 3"			123.3+5' 3-	2' 8" 1/2=	153.8 in
5/9/02	10:30		1' 6 3/4"	No Leak		1094.58		
5/9/02	10:30	fuel delivery	250 gallons		8.0 gal/in		1500	
5/9/02	11:21		4' 2"			153.8+4' 2" -	1' 6 3/4" =	185.05 in
5/9/02	11:50	1502.3						
5/10/02	11:30		3' 11 3/4"			1112.817		
5/11/02	11:43		3' 9 1/2"			1131.053		
5/11/02	11:55	1550.1						
5/28/02	10:20		11"			1,410.675		
5/28/02	10:24	1945.0		No Leak				
5/28/02	10:25	fuel delivery	250 gallons		8.13 gal/in		1750	
5/28/02	11:23		3' 5 3/4"			185.05+3' 5	3/4" - 11" =	215.8 in
5/28/02	11:25	1946.9						
6/11/02	10:08	2279.0						
6/11/02	10:13		1' 2 1/2"	No Leak		1,631.59		
6/11/02	11:27	fuel delivery	250 gallons		8.19 gal/in		2000	
6/11/02	13:05		3' 9"			215.8+3' 9" -	1' 2 1/2" =	246.3 in
6/17/02	17:02	2428.8						
6/17/02	17:08		2' 9"			1,728.792		
6/18/02	7:46	2443.0						

Date	Time	Cumulative Hr Meter	Storage Tank Fuel Depth	Tank Leak Detector	Calculation Cal gal/in	Calculated Gal Used	Cumulative Gal Del	
6/18/02	11:21		2' 7 1/4"	No Leak		1,742.98		
6/18/02	11:49	fuel delivery	250 gallons		8.00 gal/in		2250	
6/18/02	12:35		5' 2 1/2"		246.3 + 5' 2	1/2" - 2' 7	1/2" =	277.55 in
7/8/02	10:55	2920.0						
7/8/02	11:16		1' 11 1/4"			2,061.10		
7/9/02	11:15		1' 9 3/4"	No Leak		2,073.26		
7/9/02	13:20	fuel delivery	250 gallons		8.19 gal/in		2500	
7/9/02	14:12		4' 4 1/4"			277.55 + 4'4	1/4"-1' 9 3/4	" = 308.05 in
7/20/02	10:00	3124.1						
7/20/02	11:31		3' 1/2"	No Leak		2,200.93		
7/23/02	12:44	fuel delivery	235 gallons	at 8.105	couldn't take	all of del	2750	
7/23/02	12:51		65 1/2"			308.05 + 65	5 - 3' 1/2" =	337.05 in
8/13/02	10:55	3603.8	1' 10 1/4"	No Leak		2,551.45		
8/13/02	11:24	fuel delivery	265 gallons	at 8.105	this is 250 +	left over	3000	
8/13/02	12:03		4' 7 1/4"		337.05 +4' 7	1/4" - 1' 10	1/4" =	370.05 in
8/27/02	10:14	3932.9	2' 3"	No Leak		2,780.42		
8/27/02	10:21	fuel delivery	250 gallons				3250	
8/27/02	11:12		4' 10"			370.05 + 4'	10" - 2' 3" =	401.05 in
9/10/02	10:21	4090.4	3' 8 3/4"	system shut	down.	2,887.81	3250	
				End of test.				
11/5/02	16:26		3' 8 1/2"	lost 1/4 inch	evaporation	2,889.81	3250	
11/6/02	C&M pump	ed out 286	gal by their	measure	Acutal amt			
		pumper out	using 8.105	gal per in	is 361 gal.			
		Mr W. Barnes	was on site	and was	advised of			
		the descripen	cy at the	time.				
						add 361 pumped out		
11/6/02		4090.4	0			3250.81	3250	

Final Fuel Note

Final Fuel 2889.1 gal	plus 361	pumped out equals	3250.81 gallons

This accounts in total for the 3250 gallons of fuel brought on the premises of Fort Story Facility.

CALCULATIONS OF FUEL PER INCH IN TANK

Date Delivered	Gallons delivered	Gallons calculated	Fuel depth measured	Gal / inch calculation
2/21/02	500		61.5	8.13
3/19/02	250		32	*1 note
4/4/02	250		31	8.065
4/18/02	250		30.5	8.197
5/9/62	250		31.25	8
5/28/02	250		30.75	8.13
6/11/02	250		30.5	8.197
6/18/02	250		31.25	8
7/9/02	250		30.5	8.197
7/23/02	The deliver of 7/23 & 8/13		*Note 1	
8/13/02	totals 500 gal. Used together		*Note 2	8.065
8/27/02	250		31	8.065
Total fuel measured			3,151 Average	8.105 g/I

*Note 1 These values were used together in the avg calculation because the delivery on 7/23 would not fit. The remainder of that delivery was in 8/13's.

*Note 2 This measurement was not used because the depth just prior to the delivery was estimated and not actually measured.